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BIG HILL SALT DOME, MATAGORDA COUNTY, TEXAS

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ABSTRACT

Big Hill, Matagorda, is a characteristic Gulf Coast salt dome and has a distinct salt-dome mound, a subcircular salt core intruded into Tertiary sediments and a thick cap on the top of the salt. The cap contains an extensive and important deposit of sulphur. The cap is composed of (*a*) a "barren cap" of limestone above, (*b*) the sulphur-bearing zone composed chiefly of limestone and grading below into (*c*) a thick deposit of barren anhydrite. The sulphur is secondary and later than the limestone and anhydrite. The sulphur is mined by the Frasch process in which superheated water is pumped down through a drilled well; the melted sulphur is collected at the bottom of the well and pumped to the surface by an air lift. A review is given of the possible reactions for the formation of the sulphur. On account of the lack of extensive drilling, little is known about flanks of the dome, a small amount of oil was produced in the early days, mostly from the top of the cap.

INTRODUCTION

Big Hill, Matagorda County, Texas, is 1 mile from the shore of Matagorda Bay, about midway on the county's coast line, and 20 miles south-southeast of Bay City. A branch line of the Gulf, Colorado and Santa Fe Railway extends to the sulphur mine of the Texas Gulf Sulphur Company now operating there.

This dome has been little prospected for petroleum; few deep holes have been drilled as compared with the other coastal domes, and little paleontological work has been done on the deeper sediments. The age of the dome and the stratigraphy of the deeper surrounding sediments, therefore, are correspondingly somewhat uncertain. Big Hill (now known also as Gulf) is famous for its sulphur output, not for oil production, and, accordingly, far more is known about the cap

rock and the sediments immediately overlying it than about the deeper strata.

HISTORY

Big Hill, after proving an early failure as an oil field, was neglected for a time, and then, within the space of a few years, was developed into one of the world's most important sulphur producers. This was one of a group of topographically prominent domes drilled immediately after the Spindletop boom. William Cash and W. T. Goode were probably the men who first conceived the idea of drilling Big Hill for oil. Sometime during 1901 they acquired about 1,500 acres on and around the hill, and let a drilling contract. Work started at the north end of Block 94, William Simpson League, on the southeast slope of the hill. This first well was drilled in during January, 1902, to about 840 feet, and was a tremendous gasser. All estimates of its production were mere guesses, but the assertion is made that millions of cubic feet of gas per day escaped for a period of several months. This gas was chiefly hydrogen sulphide, an indication of the chief mineral of the dome. Some use was made of the gas, but the major portion of it was wasted.

The Cash and Mayes Syndicate, as the partnership was called, drilled two more wells on the hill to the north of the discovery well, but without success. A short time later T. W. Lane and John Sutherland, of Bay City, formed the Lane-Sutherland Syndicate and drilled a well near the center of Block 78, William Simpson League, north of the Cash and Mayes wells and on the east slope of the hill. A little oil and, what has since proved to be more important, a great thickness of sulphur-bearing limestone, beginning at 900 feet, were found. The well was abandoned in salt water at 1,200 feet.

Mr. Lane sold out to Dr. P. S. Griffith, who made a new location on top of the hill in Block 70, William Simpson League. In May, 1904, this well blew out at 850 feet after penetrating the cap rock a very short distance. The well began flowing at an estimated rate of 2,500 barrels of oil and 3,000 to 4,000 barrels of water per day. The Griffith well served to stimulate immediate activity, and oil production increased until, in December of that year, the average daily output was said to be 4,000 barrels. Salt water then appeared in almost every well, and, by late in December, in such quantity as to decrease the oil production to 1,200 barrels per day. By February, 1905, the production had fallen off to 400 barrels per day.

The boom in the Humble field early in 1905 caused the almost complete desertion of Big Hill. John Sutherland alone remained, pumping several wells by means of windmills and making from 150 to 200 barrels of oil per day. The big storm in the autumn of that year blew down all the derricks, and oil production practically ceased.

Sulphur was found in many places in the drilling of the numerous wells on the hill. These discoveries were merely incidental to the search for oil, but the

existence of sulphur was remembered, and this knowledge gave fresh impetus to exploratory work four years later.

In 1909, A. C. Einstein and John W. Harrison, who without very much success were prospecting for sulphur south of Liberty, Texas, decided to drill Big Hill. Their driller, Dr. A. L. Lyons, now of Vinton, Louisiana, took the contract. The first real test for sulphur was made on the northeast slope of the hill, on land of the Matagorda Oil Company, which had acquired the Sutherland, Griffith, and other interests. The results of this well were sufficiently encouraging to cause the formation of the Gulf Sulphur Company, capitalized at $250,000, and the drilling of a series of test wells. All of these wells showed large amounts of sulphur.

Bernard M. Baruch and Seeley W. Mudd became interested in the sulphur possibilities of Big Hill during the year 1910 or 1911. This was not their first venture in sulphur, as they had previously investigated Bryan Heights before it was taken over by the Swenson interests. A thorough drilling and sampling of the sulphur-bearing cap rock of the dome was begun in September, 1916, by Spencer C. Browne, who had sampled Freeport for Baruch and Mudd. The work resulted in the development of one of the largest and most accessible sulphur deposits in the world.

On July 16, 1918, the Texas Gulf Sulphur Company was chartered, succeeding the Gulf Sulphur Company. The capital stock was initially 500,000 shares of $10 par value, but was later increased to 635,000 shares. At first the company could not undertake mining operations and the extensive construction that such work would necessitate because of the scarcity of materials; but the increasing demand for sulphur, due to the prolongation of the world-war, made advisable an immediate start in building. Priority rights were obtained from the government for supplies, and in the face of an extreme shortage of structural materials and machinery the construction of the plant was started in July, 1918, and completed in March, 1919.

The first sulphur was brought to the surface on March 19, 1919, and production has been carried on continuously since then with great success. The Texas Gulf Sulphur Company has become one of the three greatest sulphur producers in the world.

PHYSIOGRAPHY

Big Hill stands one mile from Matagorda Bay in an almost treeless plain that stretches from the wooded "bottom" of Colorado River, 5 miles west of the hill, to Caney Creek, about 14 miles to the east. The land along the bay shore south of the hill rises rather abruptly several feet, then slopes gradually upward, gaining an elevation of 50 feet in about 20 miles. The streams, such as Big Boggy, Peyton, and Caney creeks, have cut down almost to sea-

level and formed steep banks in the upper parts of their courses. These are the only topographic features other than the dome itself. There is nothing unusual about the drainage of this area. Some of the water flowing from Big Hill reaches Little Boggy, the nearest stream, 1⅓ miles to the west. The major portion of the drainage, however, flows directly into the bay.

The mound at Big Hill is roughly oval in shape, elongated in a north and south direction, and measured on the 20-foot contour above sea-level is 4,000 feet long by 2,400 feet wide. It rose to an elevation of 37 feet at its summit before sulphur-mining began. The 22-foot contour line (Fig. 1) shows the true outline of the mound.

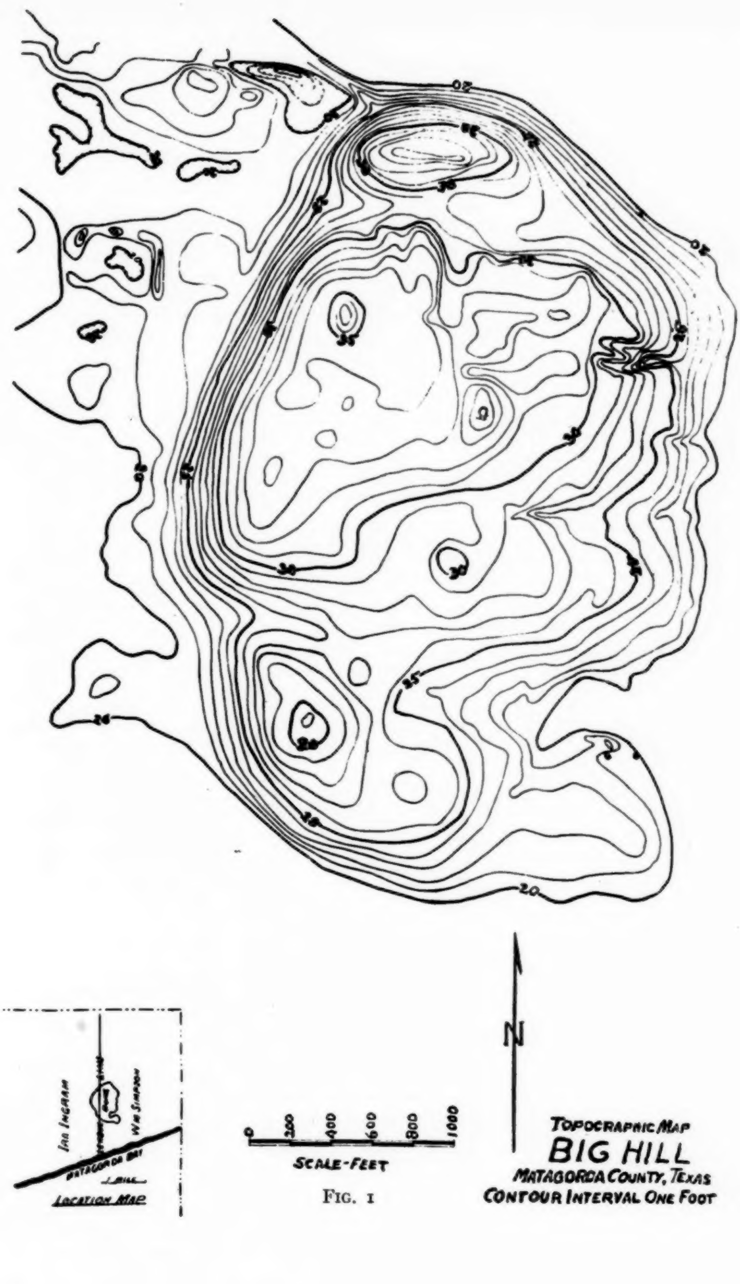
In the immediately surrounding country are numerous small ponds and so-called "gas mounds," the latter, in the writer's opinion, being erosion features. Some of these ponds are shown on the northwest part of the contour map.

SURFACE GEOLOGY

The surface material of the mound consists of a yellow clay belonging to the Beaumont. It contains numerous small, dark-colored nodules with considerable iron and manganese. There are also some sandy spots on the surface. The same yellow clay with the same nodules can be found in other places, such as Peyton Creek, 10 miles to the north. At the north end of the hill, on a prominent point that shows quite clearly on the topographic map, the surface is covered by a red clay containing calcareous nodules, probably a variation of the Beaumont. Beyond the dome area the greater part of the surface is "black land," except along the bay front where a natural shell reef has been formed.

SUBSURFACE GEOLOGY

Big Hill is a typical example of a Gulf Coastal salt dome, and has the surface mound and the unconsolidated sediments overlying a salt plug that is capped with a layer of calcium minerals and that has been thrust up through the deeper surrounding strata. In the early days when cap-rock oil was sought, there was little incentive to drill through the cap to the salt plug, and since sulphur-mining has started, such a practice would be disastrous. Therefore little is



Topographic Map
BIG HILL
Matagorda County, Texas
Contour Interval One Foot
Scale-Feet
0 200 400 600 800 1000
N
Location Map
Matagorda Bay
Ira Ingram
Wm Simpson
20
25

FIG. 1

known about the true shape of this salt core or plug. Such data as are available indicate that the highest part of the plug is about 1,300 feet below sea-level, and that the top of the plug is almost flat, sloping only very gently toward the edges, then suddenly dropping away at a steep angle. As the core is not definitely outlined by drill holes, its size cannot be stated with any degree of accuracy. It is probably elliptical in shape, with an east-west axis of about 4,000 feet, and a north-south axis somewhat longer. The top of the salt, so far as known, and the top of the cap correspond fairly well with the surface topography.

The cap rock is the all-important part of Big Hill. It extends over the entire flattened top of the salt core and down over the flanks of the core a short distance. It underlies more than 300 acres. As its highest point at the center is just 800 feet below sea-level and the salt 1,300 feet, the thickness of the cap is approximately 500 feet at the center. From the center, it thins slightly toward the edges, and pinches out suddenly where it laps over the flanks of the core. Its top is shaped somewhat like the top of the plug, except that its slope is steeper. At the edges of the cap, the slope is abrupt. The steepest slope is on the north.

The cap rock is divided into three parts. On top is a thin layer or zone of porous limestone, barren of sulphur and containing much calcite, and, in the parlance of the sulphur-miner, called the "cap rock." Underlying this is a zone of varying thickness, consisting of limestone identical with that of the cap rock, except that it contains a varying percentage of native sulphur. Beneath the sulphur-bearing horizon, but not so clearly divided from it as the cap rock, there is a very large deposit of anhydrite. The sulphur zone merges into the anhydrite, some residual anhydrite being found in the limestone and sulphur zone, the percentage of calcium sulphate increasing with greater depth while calcium carbonate and sulphur decrease, until anhydrite with only minute crystals of sulphur and microscopic particles of lime is found. Because of this gradual transition, the bottom of the sulphur-bearing zone cannot be sharply defined, and the thickness of the sulphur body depends more on the amount than on the mere presence or absence of sulphur. In some parts of the sulphur pay zone there is a thin lense of barren anhydrite with more

sulphur-bearing limestone below it, and the ore fades out into the main body of barren anhydrite at greater depth. Such an occurrence is rare, but interesting, for it appears to be a residual portion of the unaltered calcium sulphate in the secondary limestone and sulphur, and is repeated many times on a very much smaller scale throughout the sulphur zone.

The main features of the dome are illustrated in the accompanying section (Fig. 2). The position of the top of the cap is established fairly definitely, and is so indicated. The limestone-and-sulphur horizon is shown merging into the anhydrite below. The limestone is

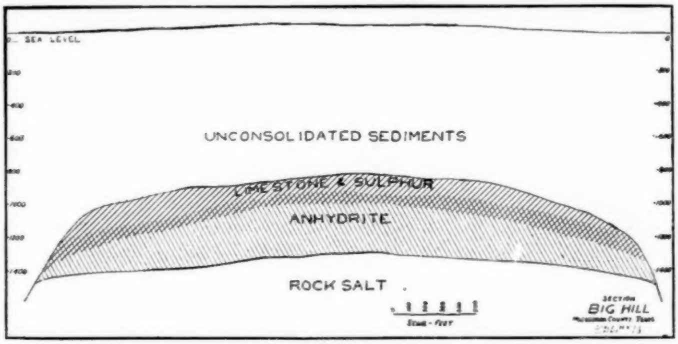


FIG. 2

hatched to the left, the anhydrite to the right, and the intermediate zone, which in some cases is sulphur ore and in others practically barren anhydrite, is shown by the cross-hatched area. No attempt has been made to show the barren limestone layer above the sulphur zone, the cap rock of the sulphur mine, because, in general, it is too thin to show on the drawing. Below the anhydrite is the great rock-salt core.

A partial analysis of a sample from the sulphur-bearing zone is shown in Table I. The probable combination is approximated after correcting the analysis for the iron oxide introduced by pipe scale.

MINERALS IN THE CAP ROCK

Mineralogically the cap is extremely interesting, as economically it is of great importance, and it is far more complex in composition than first appears on cursory inspection.

Sulphur.—The sulphur occurs in massive form in layers and as the filling of irregularly shaped cavities which sometimes are several feet in diameter; in little bunches, specks, and veinlets; and in beautiful orthorhombic crystals, lining vugs. The crystals sometimes occur in the simple pyramidal form, but usually that is modified by a basal pinacoid and by a second pyramid or a brachydome. The color of the sulphur ranges from a bright canary-yellow in both the crystalline and massive forms to dark-brownish and greenish tints in the massive form. It is all extremely pure, and color is no indication of any appreciable percentage of foreign matter.

Calcite.—Well-crystallized calcite constitutes a considerable percentage of the sulphur-bearing zone and of the barren cap rock. It

TABLE I

Analysis of Sample of Big Hill Cap Rock from Sulphur-bearing Zone

Analysis	Per Cent	Probable Combination	Per Cent
Silica and insoluble	1.2	Silica and insoluble	1.4
Iron and aluminum oxides	15.0	Calcium carbonate	48.1
Calcium	18.9	Magnesium carbonate	2.63
Magnesium	0.65	Calcium sulphate	9.47
CO_3	26.6		

occurs as veinlets between bunches of sulphur, veinlets running in all directions through the limestone, and as the lining of vugs. It crystallizes both as rhombohedrons and scalenohedrons, and in color varies from colorless and white to amber. Some of the calcite has been recrystallized. As limestone, it makes up the main body of the sulphur zone exclusive of the sulphur. The color of the limestone is usually gray. In some places the limestone, calcite, and sulphur are in minute, parallel bands, interspersed with vugs lined by calcite and sulphur crystals. In other places there is a distinct brecciated structure with sharp, angular fragments of limestone cemented together by calcite and sulphur. Figure 3 illustrates this clearly.

Anhydrite.—Anhydrous calcium sulphate constitutes about 95 per cent of the rock mass between the sulphur zone and the rock salt. It also occurs throughout the sulphur-bearing horizon in a small amount, and can be recognized under the microscope. According to Tomlinson,[1] its texture is crystalline; structure, bedded; origin,

[1] Harold W. Tomlinson, Swarthmore, Pa., special investigation.

precipitate; and metamorphosis, dehydration and deoxidation. It consists of a mass of minute particles with pseudocubic cleavage, the whole having a sugary texture. Dr. J. A. Udden states that specimens showed an irregularly banded structure; that the bands of light-gray and gray anhydrite undulated and ranged in width from mere streaks to 15 millimeters in thickness; and that the light-gray mineral was more finely crystalline than the darker-colored. The chief impurities in the anhydrite are minute crystals of pyrite, small crystals and bunches of crystals of sulphur, and microscopic crystals of calcite.

Strontium minerals.—Both celestite and strontianite occur in the sulphur zone and its cap rock. One piece of sulphur ore contained 35 per cent celestite in small, perfect crystals; and another, 10 per cent strontianite in small veinlets cutting through the calcite. As it is difficult to distinguish microscopically between calcite and strontianite in the same specimen, the estimate of 10 per cent strontianite may not be very accurate (Tomlinson). Granular pyrite occurs in some of the celestite crystals.

Magnesium minerals.—Some magnesium is present in the sulphur horizon, as much as 2.5 per cent in some specimens, but no magnesium minerals have been recognized. Analyses indicate a probable combination in the form of magnesite or dolomite. The percentage of magnesium in no case is sufficient to justify applying the name "dolomite" to any part of the cap rock.

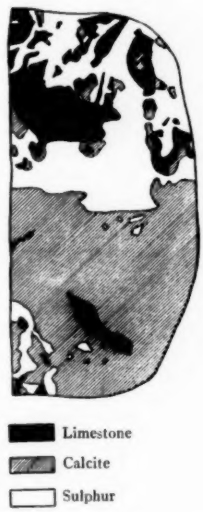


FIG. 3.—Cross-section of core.

Barite.—One specimen from the sulphur zone contained 30 per cent of barium sulphate.

Sulphide minerals.—Pyrite, galena, and sphalerite have been found in the Big Hill cap rock. Pyrite is present through the cap rock from the top of the deepest anhydrite sampled. It occurs in the upper part of the cap in minute crystals, veinlets, and masses. Individual crystals in a few cases are large enough to be recognized by the unaided eye.

Galena is present in small crystalline bunches, associated with pyrite, in the limestone. One selected specimen assayed 0.53 per cent lead, equivalent to 0.6 per cent galena. Well-formed cubes of galena up to 2 millimeters were found also in some sandstone at a depth of 1,600 feet on the outer edge of the dome.

Only one small particle of sphalerite, so far as known, has been observed. No assays have been made for zinc in specimens of cap rock.

Quartz.—Fractional percentages of silica occur in the limestone and anhydrite. Limestone from the sulphur horizon digested in acid left perfect, double-pyramidal quartz crystals $\frac{1}{8}$ – $\frac{1}{32}$ millimeter in length (Udden).

UNCONSOLIDATED SEDIMENTS

The sediments above the cap rock can be classified as clays, sands, and marls. Dr. Udden made an exhaustive study of the logs of sixty-two wells drilled within the area of the Big Hill rock and the aggregate 60,000 feet of drilling represented by these reports were classified, according to the drillers' terminology, as follows:

TABLE II

AGGREGATE THICKNESS OF ROCK TYPES REPORTED IN SIXTY-TWO BIG HILL WELL RECORDS

Formation	Total Feet Drilled	Per Cent of Total Drilled
Gumbo	30,701	49.6
Shale	8,865	14.3
Clay	6,244	10.1
Sand	11,394	18.4
Gravel	874	1.4
Shell	656	1.1
Rock	3,148	5.1
Total	61,882	....

These are the main divisions, including such subdivisions under each heading as "gumbo and bowlders," "clay and sand," "shale, shell, and sand." This summary is of interest because it shows the relative amounts of the various materials found in the supercap zone.

Rock, as classified above, ranges from slightly hardened concretions through all gradations of sandy limestone and sand cemented

by lime. The total footage of rock shown does not lie in a few well-defined strata overlying the entire cap-rock area, but in a great number of lenses, small in extent, and usually quite thin. Rarely does a rock stratum found in one well extend laterally 100 feet in any direction. In the sixty-two wells, 406 beds of rock were reported. Their thickness and distribution are shown in Tables III and IV prepared by Dr. Udden.

This shows that more than one-half the total amount of rock reported in these sixty-two wells is within 50 feet immediately above the cap rock. Any rock reported over 550 feet above the cap is insignificant in amount. These conditions are probably representative of the entire area of the dome. The distribution of thickness of individual beds is given in Table IV.

TABLE III

Distribution and Thickness of Rock in Sixty-two Big Hill Wells

Distance above Sulphur in Feet	Per Cent of Rock in Each 50 Feet	Total Footage of Rock in Each Division
550–500	0.3	10
500–450	0.2	9
450–400	0.3	12
400–350	0.9	28
350–300	2.7	86
300–250	4.0	133
250–200	9.1	283
200–150	18.3	569
150–100	12.8	399
100– 50	11.7	369
50– 0	53.7	1,665

Of the numerous strata found in the hundred or more wells drilled on the dome, only three appear to be at all continuous. These are the surface clay, the shallow sand just under the surface clay, and the thick gumbo stratum immediately overlying the dome cap rock. The intermediate strata are flat lying and extend only short distances, apparently not over 100 feet laterally. Apparently they are lense shaped, overlapping one another like shingles on a roof. Part of this seeming irregularity, no doubt, is due to the difficulty in logging correctly a number of thin strata drilled rapidly by the rotary

method and by different drillers; but there can be little question of the existence of great irregularity in the bedding of these recent deposits.

Considerable paleontological work has been done on the supercap sediments, but though it is certain that the uppermost beds are Pleistocene, no definite opinions have been obtained regarding the probable dividing lines between the deposits of various ages. That some of the sediments overlying the dome are Pliocene, and possibly

TABLE IV

DISTRIBUTION OF THICKNESS OF ROCK STRATA AT BIG HILL

Thickness of Individual Beds in Feet	Per Cent of Total Number of Beds Reported (406)	Per Cent of Total Footage Reported (3,563)
1– 5	56.0	21.2
6–10	23.8	23.6
11–15	7.6	12.3
16–20	4.1	9.5
21–25	2.4	6.1
26–30	2.7	9.6
31–85	0.85	19.2

even older, is almost certain, for Pliocene beds are known to be relatively high in this part of the Gulf Coastal plain. The problem of distinguishing between the Pleistocene and Pliocene deposits in Texas is difficult,[1] so it is not surprising that it has not been definitely solved at Gulf. The following tabulation shows some of the fossils found above the cap rock at Big Hill and the depths at which they were found. The determinations were made by the Bureau of Economic Geology and Technology, University of Texas, Austin:

FOSSILS FROM THE SUPERCAP SEDIMENTS AT BIG HILL

Depth Below Sea Level in Feet	Fossils Identified
100–150	Ostracods, *Chara* fruit case, *Rotalia*-like Foraminifera less than ½ millimeter in size
150–180	*Rotalia*-like Foraminifera, one *Anomalina*
180–200	Fragments of barnacles, small pelecypod, smooth ostracod, gastropod, and *Rotalia* sp. and *Polystomella* cf. *craticulata* (Pliocene?)

[1] J. A. Udden, C. L. Baker, and Emil Böse, "Review of the Geology of Texas," *Bulletin 44* (1916), p. 121.

Depth Below Sea Level in Feet	Fossils Identified
200–250	Shreds of lignitic material, pelecypods, minute *Polystomella*
250–350	Thin mollusk-shell fragments, limonitic shreds of vegetal matter
At 350	*Ostrea* conglomerate consisting of shells imbedded in a marly matrix in part slightly indurated. Also *Rotalia* sp. and *Polystomella* sp., molds of large portions of *Mytilus* shells. (Might be Pliocene?)
350–500	Oyster-shell fragments, soft lignite
540–550	Pelecypods, gastropods, fish scales, teeth, Foraminifera including *Rotalia*, *Polystomella*, and *Anomalina*
640–680	Barnacle-shell fragments, oyster shells, pelecypod shells, ostracod valves, Foraminifera resembling *Rotalia*, *Polystomella* (sp?)
770–780	Barnacle fragments
812–	Fragments of oyster shells

Little deep drilling has been done at Big Hill, and the structure of the surrounding beds, has not been established precisely. There is little doubt, however, that the lower beds dip in all directions away from the core at a high angle near the dome. Insufficient information has been collected to warrant any statements regarding the stratigraphy of the deeper beds. These lateral sediments consist largely of gumbo and shale, to use the drillers' terminology, with some marl and sandy marl. "Black shale," similar to that at West Columbia, Damon Mound, and elsewhere, has been found here at depth. According to Joseph A. Cushman, gumbo samples from about 1,600 feet in one well on the edge of the dome contained Foraminifera strongly suggesting either Lower Oligocene or Upper Eocene, with the probabilities in favor of the latter. This would indicate a considerable uplift, perhaps 3,000 feet.

AGE OF THE DOME

Nothing can be stated with any degree of assurance regarding the geological history of this dome, although it is likely that all coastal domes are of approximately the same age. If we accept the intrusive origin of the domes as correct, the major movement at Big Hill probably occurred during the Pliocene. It is doubtful if any amount of exploratory work and scientific investigation would lead to a closer estimate. If the cap rock is of secondary origin as compared with the salt core, and the writer believes that it is, part of the deformation

of the later or Pleistocene beds may have been caused by its accumulation. The age of the cap rock is equally as indeterminate as that of the core, and its relative age is dependent on the mode of formation ascribed to it. If of secondary origin, it is of course younger than the salt core. If the caps of the various domes were first deposited as anhydrite and later hydrated to gypsum,[1] where that mineral occurs, then the cap rock at Big Hill may be relatively young as compared with that at Damon Mound, for example, for no such hydration has taken place at Big Hill. If the anhydrite was formed by the dehydration of gypsum, then the cap there apparently is old as compared with many of the dome caps.

ORIGIN OF THE DOME

The possible origin of Gulf Coastal salt domes is a subject that has been discussed at too great length to be given a comprehensive review here. It is generally recognized that the subject must be approached from three standpoints: the cause of the uplift, the source of the salt, and the origin of the cap rock. The uplift has been attributed to the deposition of either the salt or of the cap rock, or, in part at least, to chemical changes in the cap rock after deposition. Little can be added to this discussion by any discovery made at Big Hill to date, except to state that the structure of the dome as a whole tends to strengthen the theory of salt intrusion.[2] A handy reference for those who wish to make a detailed study of this problem is a complete tabulation of the theories advanced to date in the writer's "The Origin of Salt Domes."[3]

The formation of the cap rock is undoubtedly secondary to the salt intrusion. Examined under the microscope, the cap-rock material proves to be a precipitate. But the presence of a warm, saturated brine makes it almost impossible to explain the deposition of gypsum from solution; and the compactness of the anhydrite suggests the improbability of the formation of this great, massive sheet by dehydra-

[1] Donald C. Barton, "The West Columbia Oil Field," *Bull. A.A.P.G.*, Vol. 5, No. 2, (March, 1921), pp. 220 and 225.

[2] G. S. Rogers, "Intrusive Origin of the Gulf Coastal Salt Domes," *Econ. Geol.*, Vol. 13 (1918), No. 6, pp. 447-86.

[3] "The Origin of Salt Domes, a Chronological Tabulation of Theories Thus Far Advanced," *Eng. and Min. Jour.-Press*, Vol. 115 No. 9, (March 3, 1923), p. 412.

tion of gypsum. Anhydrite on the other hand is formed by precipitation from sea water at 86° F., or possibly over. The brecciated structure of the upper part of the cap rock, as described under "Calcite," seems to indicate that the upthrust did not occur all at one time, but in successive movements that broke up the higher portion of the cap. Uplift followed by cementation by calcite and other minerals precipitated from circulating solutions would have produced the structure noted.

The original brine in the cap rock must have been very strong. A sample of the water coming from the mine in April, 1921, after fresh water had been pumped into the dome for two years, gave the following analysis:

TABLE V

	Grains per Gallon		Per Cent
Silica	1.2	Alkalis	40.65
Calcium sulphate	197.0	Earths	9.35
Iron and aluminum oxides	0.6	Strong acids	48.67
Calcium bicarbonate	19.0	Weak acids	1.33
Calcium chloride	431.0	Primary salinity	81.3
Magnesium chloride	189.0	Secondary salinity	16.0
Sodium chloride	3,670.0	Secondary alkalinity	2.7
Specific gravity	1.052		

OIL AND GAS

The first well drilled into cap rock at Big Hill blew in a big "gasser." Most of this gas was hydrogen sulphide, but no analyses were made to determine what proportion was "sulphur gas" and how much petroleum gas. Subsequent wells produced considerable oil, all of it from the uppermost, cavernous part of the cap rock. This oil had a greenish tint, and was of the usual coastal gravity, about 20° Baumé.

The major production of oil was made before the end of 1905, and probably did not altogether exceed 500,000 barrels. During the years 1904 to 1907 inclusive, Matagorda County produced 203,580 barrels.[1] It is certain, therefore, that the estimate of one-half million barrels is liberal. After the Texas Gulf Sulphur Company started operations in 1919, a few old wells and one new prospect well in the

[1] *The Manual for the Oil and Gas Industry* (revised to 1921, Treasury Dept. U. S. Int. Rev.), p. 218.

cap rock flowed a small amount of oil, and created a mild excitement among the uninitiated. This flow was nothing more than the "dying gasp" of the dome as a producer of cap-rock oil. The great quantity of hot water forced into the sealed structure of the dome lifted the remaining portion of the oil to the top and out through these open holes. All these wells soon went to water.

An idea still persists that improper handling of one or more of the cap-rock wells in the early days allowed a sudden incursion of salt water, which materially reduced the possible production of the field. The writer is quite certain that this theory is wrong. The salt water of the dome simply followed the oil as it was being withdrawn from this reservoir, and made its appearance in the walls when the lighter fluid was exhausted. Today there probably does not exist in the entire cap rock sufficient oil to fire a "pot" for one more shallow test.

Early failure of Big Hill to prove a second Spindletop, and the subsequent development of the great sulphur deposit, have both served to retard deep oil-well drilling and to distract attention from the possibilities of producing deep oil. Perhaps twenty wells, all told, have been drilled outside the cap-rock area to depths reported as ranging from 1,000 to over 3,000 feet. These wells were scattered over a large area, and the fact that no great oil discovery has been reported does not militate against the possibility of such a discovery in the future. Some of these wells were drilled during the early development of the oil field, and it is probable that the reported results are inaccurate, and also that the full possibilities of the areas tested are not exhausted.

The only oil production from lateral sands was made from two wells on the southeast slope of the dome in the Gulf townsite. These wells produced a few hundred barrels of the average coastal gravity, and then went to salt water. This production has been grossly overestimated by rumor. The oil may have come from a small pool that was trapped there by a late domal movement while seeping along some fault crack from a deep-seated source, possibly a black shale, toward the main reservoir in the cap rock.

SULPHUR

Many salt domes have produced oil, but to date only four have produced sulphur. Because of the tremendous importance of sulphur

to civilized man, the great deposit at Big Hill—or Gulf, as we must now call it—is of far greater moment than any amount of petroleum that ever could be produced there.

Origin of sulphur.—Sulphur deposits in general are formed by either volcanic or hot-spring activities, or are found in close association with limestone, gypsum, and anhydrite in sedimentary beds. The world's greatest sulphur bodies, those of Sicily and the Gulf Coastal region of Texas and Louisiana, belong to the latter class. As these two groups are similar in many respects, as the Sicilian deposits have been the subject of intensive study for many years, and as relatively little is known about the coastal dome formations, we are forced, in any discussion of the subject of the origin of these beds, to consider the theories advanced for the formation of the Sicilian sulphur bodies as applying to those of our salt domes. The European mines are operated by means of open cuts and underground workings which afford ample opportunity for study, but we must content ourselves, in the case of salt domes, with the meager samples brought up by the core barrel.

The following paragraph from the description of the Sicilian deposits by O. Stutzer[1] might have been written about the sulphur ore at Gulf:

> The parallel sulphur bands of these occurrences consist chiefly of compact sulphur. Occasionally they exhibit on their upper surface hollow spaces into which calcite crystals project. Sulphur crystals have also formed on this compact sulphur along these cavities. The hollow spaces, bordered below by sulphur and above by a layer of calcite, together with their accompanying crystals, have originated through secondary solution and redeposition. The beautiful sulphur, gypsum, and celestite crystals which the Sicilian mines have contributed to the mineralogical collections of the entire world are likewise secondary products, which have formed later along fissures.

It is now almost universally accepted that the sulphur was the result of the oxidation of hydrogen sulphide according to the reaction: $H_2S+O=H_2O+S$. Also, that the hydrogen sulphide was derived from the decomposition of organic material, or from the reduction of inorganic sulphates by means of organic substances. In the case of the salt domes, as with the Sicilian deposits, the great masses

[1] "The Origin of Sulphur Deposits," from an article on sulphur in *Die Wichtigsten Lagerstätten der Nicht-Erze* from translation by W. C. Phalen. Berlin: Borntraeger Bros., 1911.

of gypsum or anhydrite present make it appear most probable that the sulphates of calcium supplied the sulphur.

In discussion of the derivation of hydrogen sulphide from calcium sulphate—a complex question—several methods of derivation must be reviewed. Bischof[1] proposed the following reactions:

$$CaSO_4 + 2C = CaS + 2CO_2$$
$$CaS + CO_2 + H_2O = CaCO_3 + H_2S$$
$$H_2S + O = H_2O + S$$

To quote Lindgren:[2]

> The objection to this scheme would be that the sulphur is evidently often formed at depths of several thousand feet, and that the presence of much oxygen at such depths would be impossible; more likely the hydrogen sulphide generated from the gypsum reacts upon calcium carbonate, resulting in secondary gypsum and sulphur.

As some of the domes, at least, are open to the circulation of unlimited quantities of artesian water which might carry oxygen and carbon dioxide in solution, the foregoing objection is overcome. The immense excess of calcium sulphate over all other minerals of the cap rock combined appears to make the secondary reaction suggested by Lindgren impossible.

Riesenfeld[3] states that the reaction between gypsum and carbon below 500° C. proceeds very slowly, but is fairly rapid above 700° C., the reaction taking place according to the equation:

$$CaSO_4 + 3C = CaS + CO_2 + 2CO.$$

Similar results were obtained with the sulphates of strontium and barium, while the indifferent behavior of magnesium sulphate is explained by the heats of reaction. He also claims that CaS cannot be decomposed according to the equation (equilibrium):

$$CaS + H_2O + CO_2 \text{ to } CaCO_3 + H_2S,$$

since CaS is formed to a considerable extent at temperatures such as 700° C., at which the equilibrium is sufficiently rapidly attained.

[1] G. Bischof, *Chemie und Physikalische Geologie*, Vol. 2 (1851), pp. 144–64.

[2] Waldemar Lindgren, *Mineral Deposits* (1919), p. 384.

[3] E. H. Riesenfeld, *Jour. Prakt. Chem.*, Vol. 100 (1921), pp. 115–58.

The reduction of gypsum by methane in experiments took place according to the equation:

$$CaSO_4+CH_4=CaS+CO_2+2H_2O.$$

Dehydration of gypsum occurred below 800° C. Some calcium oxide was formed above 1,100° C., probably according to the equation:

$$CaS+H_2O=CaO+H_2S.$$

An excess of steam favored the complete removal of sulphur at 1,200°–1,300° C.; the sulphur was obtained as sulphur dioxide or free sulphur; the latter predominated in a slight excess of water, due partly to dissociation of hydrogen sulphide and partly to its reaction with water vapor.

The carbon involved in the reduction of the sulphate might be derived from petroleum. Another process of reduction was advanced by Hoppe-Seyler[1] whereby methane is the reducing agent according to the probable reaction:

$$CH_4+CaSO_4=CaCO_3+H_2S+H_2O.$$

Kreummer and Ewald[2] stated that the walls of a cavity in gypsum in the Baringhausen mine showed alteration to calcite and impregnation with bitumen to a depth of several centimeters, and were covered by numerous sulphur crystals. Gases in the cavity were hydrocarbons and a trace of hydrogen sulphide. Sulphur was formed evidently by the reactions:

$$CaSO_4+CH_4=CaCO_3+H_2S+H_2O$$
$$H_2S+O=H_2O+S$$

It is quite easy to conceive that methane in quantity might have existed in the sealed dome at Gulf, where some oil was present. One objection to the carbonaceous reduction theory is the high temperature necessary to the reaction. It is within the bounds of reason, however, to assume that great heat was produced by upward movements of the salt plug.

[1] *Zeitschrift für Physiol. Chemie*, Bd. 10 (1886), S. 401.

[2] A. W. Kreummer and R. Ewald, *Centr. Min.* (1912), pp. 638–40.

Another method proposed for the derivation of hydrogen sulphide from calcium sulphate is by bacterial reduction. Certain micro-organisms, anaerobic bacteria, reduce sulphates and liberate hydrogen sulphide. The first exhaustive study of sulphate-reducing bacteria was made by Beyerinck.[1] A thorough exposition of this theory is given by Hunt[2] in his paper, "The Origin of the Sulphur Deposits of Sicily." To quote from this work:

> Such a bacterial reduction theory, with its accompanying chemical reactions, would explain the presence of disseminated and banded sulphur in the limestone, the unusual absence of the sulphur-limestone rock in the gypsum above, and the formation of the sulphur at normal temperatures and under conditions which would confine its formation and deposition to these land-locked basins.

This might well apply to the Sicilian deposits which could have been formed in shallow lagoons; but to attribute this mode of sulphur formation to our coastal dome deposits would necessitate a return to one of the apparently untenable theories of the building up of the salt structure concurrently with the surrounding sediments.

According to studies by Baker,[3] the oxidation of hydrogen sulphide where oxygen is in excess, as at the surface, is complete, and sulphuric acid results; but below the surface, where oxygen is deficient, sulphur is liberated.

Another tentative theory that has been advanced may be expressed in the following equations:

$$2CaSO_4+4C=2CaS+4CO_2,$$

or

$$2CaSO_4+8C=2CaS+8CO.$$

These reactions could take place outside the dome area. Water might then take the calcium sulphide into solution:

$$2CaS+2H_2O=Ca(SH)_2+Ca(OH)_2,$$

the hydrate precipitating and the calcium hydrosulphide remaining in solution until it comes into contact with water charged with carbon dioxide, when it would be precipitated:

$$Ca(SH)_2+CO_2+H_2O=CaCO_3+2H_2S.$$

[1] W. M. Beyerinck, *Centralbl. f. Bakt., 2d Abt.*, Vol. 1 (1895), pp. 49, 104.

[2] Walter F. Hunt, *Econ. Geol.*, Vol. 10, No. 6, pp. 543–79.

[3] G. F. Baker, *Monograph, U. S. Geol. Surv.*, Vol. 13 (1888), p. 576.

The hydrogen sulphide would then have to be oxidized, with the formation of water and the liberation of sulphur. Considerable chemical research is necessary to prove even the possibility of this theory.

One almost insurmountable argument in favor of the theory that the sulphur was formed in place from the reduction of calcium sulphate, with the resulting formation of calcium carbonate and native sulphur, is the relative proportion between the calcium carbonate and the calcium sulphate and the sulphur, as shown by a series of analyses of the sulphur body at Gulf from various depths. The carbonate increases and the sulphate decreases with an increase in the amount of sulphur present.

Minor structural details of the sulphur body could be explained by the breaking up of the rock due to upward movements of the core, alteration of the calcium sulphate in place, and the deposition of calcium carbonate and sulphur in the interstices. Slight movements tending to fracture the top of the cap might have taken place coincidently with the formation of sulphur. The finely laminated part of this deposit, where the layers of limestone, calcite, and sulphur alternate, might conceivably be due to the banded structure of the anhydrite and the variation of its texture in these bands.

SAMPLING

Although sulphur is extracted from the deposit through wells like those drilled for petroleum, its recovery is essentially a mining process; to carry on successful operations, therefore, it is necessary to know the grade of the ore. Sulphur sampling in general is accomplished by drilling wells to the cap rock, and then recovering the portion of the sulphur-bearing formation drilled through, by one of several different processes, such as completing the hole with water instead of mud as the circulating medium and catching the cuttings; by reversing the flow, with or without the addition of extra water, and collecting the cuttings; or by coring.

At Gulf the well drilled for sampling is first sunk to cap rock by the usual rotary method. A core is taken to make sure of the character of the formation. Casing is set on rock to cut off all material from above, and all mud is washed from the hole.

Because of the porous nature of the deposit, much of the cuttings

and drilling water would be lost if the water forced down through the drill stem were relied on for "returns." Coring is also unsatisfactory, because of the friable nature of the minerals. These conditions make it necessary to reverse the flow in the well, drawing the cuttings as fast as they are formed, along with the drilling water, up through the drill stem. This is done by means of an air lift within the drill pipe.

A hole is drilled in the top of the goose-neck of the swivel, and around it a seat is machined for a light swivel which supports the air line. From 250 to 300 feet of $\frac{1}{2}$-inch galvanized pipe, with left-hand threads, is run into the stem, and the air line is connected with any source of compressed air under 120 pounds pressure. The ordinary fish-tail bit is used, but with holes enlarged to $1\frac{1}{4}$ inches to reduce the possibility of clogging by large cuttings. As a rule, no water is needed; sufficient comes in from the formation. When necessary, it is run into the top of the casing. As drilling proceeds the compressed air released into the $\frac{1}{2}$-inch line forms an air lift inside the drill stem and the cuttings are drawn into the stem through the holes in the bit and forced out through the hose leading from the goose-neck of the swivel. These cuttings are carefully collected on a screen and in a series of settling boxes fitted with baffles in such a manner that even the finest cuttings are forced under the surface of the water and saved.

This method of sampling sulphur-bearing rock was developed by Spencer C. Browne, a mining engineer of New York City, during the early exploration of the sulphur deposit at Bryan Mound, Brazoria County, Texas. The advantages of the method are rapidity, accuracy, and flexibility. Samples from any footage of the formation can be taken, and the cuttings of each sample can be kept separate by allowing sufficient time for the hole to wash clean. Samples are first carefully dried on a water-bath so as not to fuse any of the sulphur, and are then cut down, and assayed. The reject is saved for future reference.

SULPHUR-MINING

Herman Frasch in 1891 invented the process of extraction now used in all Gulf Coastal sulphur mines. It embodies the ideas of melting the sulphur in the ground by means of superheated water, and raising the sulphur in a molten state to the surface of the earth.

Pumps were first used for the latter purpose, but were soon replaced by compressed air.

Economic and large-scale extraction of sulphur by this process can be carried on only where a big sulphur deposit of good grade occurs under favorable geological conditions. In addition to the natural requirements, a boiler plant of large horse-power, together with water heaters, high-pressure pumps, and air compressors are necessary to supply the enormous volume of hot water under pressure, and the compressed air; as well as drilling equipment and a thoroughly trained crew to sink, equip, and operate the sulphur wells.

At Gulf, a well is sunk rapidly to cap rock; a carefully drawn cap-rock contour map aids materially in predicting where it will be struck. Eight-inch casing is set, and the hole is drilled to the bottom of the sulphur-bearing formation. The well is then ready for the equipment, which consists of a 6-inch, a 3-inch, and a 1-inch line, all set concentrically, and connected with each other above the surface by expansion joints.

Two groups of holes are drilled in the 6-inch pipe, near the bottom and a few feet apart. The lower group constitutes the sulphur "strainer," where the molten sulphur flows into the pipe, and it is so placed that it will be at the very bottom of the sulphur pay. The upper group of holes serves as an outlet for the hot water. Between these two groups of holes is a seat that supports the string of 3-inch pipe. The 1-inch pipe is supported from the top, and extends to within approximately 20 feet of the bottom of the 3-inch string.

In "steaming" a well, water heated in the plant to about 325° F. is forced down between the 3-inch and 6-inch pipes under 95–250 pounds' pressure. The sulphur melts and runs to the bottom of the well, as its specific gravity is about twice that of the water. From there, it is forced part way up the 3-inch pipe by the water pressure, and elevated to the surface by compressed air under 500 pounds' pressure, which is released from the bottom of the 1-inch line. Under certain conditions, some wells will pump steadily while "taking water"; others will not. When the molten sulphur ceases to "pump," the water comes up through the 3-inch pipe and flashes into steam. The well is then said to "blow." Air is cut off, and water alone must

be pumped into the well for a number of hours until more molten sulphur has collected at the strainer. If the well then pumps sulphur, it is said to have "sealed." While the well is not pumping sulphur, water can be forced in through the 3-inch pipe as well as through the 6-inch and accelerate the melting process.

The liquid sulphur is conducted from the wells to the vats through pipes fitted with an inner steam pipe. The vats are built of lumber and are of light construction, as the sulphur solidifies almost as fast as it is run into them. The vats vary in size, but are now built up to about 50 feet in height. A single vat at Gulf contained at one time about one million tons in a single block. When a vat is filled, the wood forms are torn down. Vertical holes are drilled several feet back from the face by a specially designed, light rotary rig. The holes are sprung with light charges of dynamite, and then shot with heavier charges. Electric firing is employed. The broken sulphur is loaded into gondolas by locomotive cranes, and into box cars by cranes and Ottumwa box-car loaders. The details of handling sulphur after it is won from the earth is beyond the province of this paper.

The mine-water heating plant contains fourteen Sterling water-tube boilers of 702 horse-power each, eight jet-type water heaters, thirty-four duplex slide-valve pressure-pumps, and six Laidlaw-Dunn-Gordon compressors. The boilers supply steam to the water heaters, to the compressors, turbo-generators, and the various pumps. One-half the pressure-pumps force water into the heaters against the steam pressure of the boilers, and the other half, called the "booster pumps," send the water to the wells under pressures up to 250 pounds when necessary. The heaters raise the temperature of the mining water to nearly the temperature of live steam under 95–105 pounds, pressure, approximately 325° to 335° F.

The plant was designed with the expectation that it would produce 1,000 tons of sulphur per day. This anticipation was based on the results of the older sulphur-mining installations. But as a matter of fact, five times this amount has been produced. This phenomenal success is due in part to a careful study of every phase of the mining problem, especially of the principles of thermo-dynamics involved, and the application of every economy and simplification in the pro-

cess. Too great credit cannot be given the efficient executive and technical control of the operations. A more important reason for the unexpected success in mining operations is the existence of an enormous deposit of sulphur surrounded by almost ideal structural conditions. The deposit lies at a depth from which it is not difficult to elevate the sulphur to the surface. Its entire top is overlaid and effectually sealed on that side by a thick stratum of gumbo; the enormously thick bed of barren anhydrite serves the same purpose below. Any hot water forced into this sulphur-bearing zone is trapped, and must give up a large part of its heat. As the same volume of water introduced must be drawn off, "bleed wells" are drilled around the outer edge of the deposit and draw the waste water from a deeper and cooler zone than that in which the sulphur is being melted.

After sufficient sulphur has been removed from any given area, the porous rock remaining breaks down under the weight of the overlying sediments, and the gumbo flows into the cavity. This movement is manifested by a subsidence of the surface, and is a desirable action, because the volume once occupied by sulphur is filled by rock and gumbo, and the quantity of water required to fill the reservoir is reduced; furthermore, the hot water, restricted in its flow, is forced to circulate where a large part of its heat will be utilized in melting sulphur. The subsidence is slow and uniform, and progresses without shock, on account of a great preponderance of unconsolidated strata between the sulphur pay and the surface. If the barren limestone, the sulphur-miner's cap rock, immediately over the sulphur-impregnated limestone, were thick and capable of supporting great weight, the subsidence might conceivably take place at long intervals and with great violence, or not at all. Due to the relative thinness of the barren, but porous, limestone "cap," not much hot water is wasted in filling this part of the underground reservoir.

IMPORTANCE OF SULPHUR

Although the Gulf Coastal area is an oil-producing region of considerable importance, it does not supply more than about 5 per cent of the average daily output of the United States, and the loss of this quantity would not be a disastrous blow to the commercial

activities of the United States. Not so with sulphur, however. The three great coastal sulphur-mining companies of Texas and Louisiana furnish over 99 per cent of this mineral produced in the United States and, in round figures, 75–80 per cent of the world's production. Table VI shows the output of sulphur by the major contributing countries, and the movements of sulphur; and demonstrates quite clearly the domination of the sulphur industry of the world by these Gulf Coastal mines.

TABLE VI

World-Production and Consumption of Sulphur*

	Production			Exports and Imports			
	U.S. Long T.	Italy Met. T.	Japan Met. T.	U.S. Shipments Long T.	U.S. Exports Long T.	U.S. Imports Long T.	Italy Exports Met. T.
1909	273,983	402,353	36,317	258,283	....	26,914	364,953
1910	247,060	397,808	43,848	250,919	30,742	28,647	395,944
1911	205,066	376,161	52,064	253,795	28,103	24,250	456,227
1912	787,735	356,555	55,005	305,390	57,736	26,885	447,590
1913	491,080	345,548	59,481	319,333	89,221	14,636	414,716
1914	417,690	334,974	75,308	341,985	98,163	22,810	338,308
1915	520,582	319,260	73,369	293,803	37,271	24,647	359,806
1916	649,683	233,835	108,100	766,835	128,755	21,510	396,035
1917	1,134,412	177,453	117,990	1,120,378	152,736	973	162,971
1918	1,353,525	194,585	64,696	1,266,709	131,092	55	230,769
1919	1,190,575	181,744	67,382	678,257	224,712	77	147,286
1920	1,255,249	224,247	21,147	1,517,625	477,450	44	189,878
1921	1,879,150	240,089	33,106	954,434	285,762	4	105,542
1922	1,830,942	137,640	....	1,343,624	485,664	7,960	137,352

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A broad division of the industries using sulphur as a direct constituent of their finished products or as a reagent in their manufacture may be made as follows:

1. Acids and chemicals
2. Acid phosphate
3. Paper
4. Agriculture (other than acid phosphate)
5. Rubber
6. Galvanizing
7. Explosives

Sulphur is of considerable importance to the petroleum industry in the form of sulphuric acid used in the process of refining. An enu-

meration of all the articles indispensable to the petroleum industry that require sulphur in their process of manufacture is out of the question here, to say nothing of the innumerable things used every day by the average man; but one may be so bold as to say that the world today could as easily get along without petroleum as without sulphur. On the other hand, petroleum solved the problem of cheaper fuel for the sulphur industry, and made it possible for the Frasch process to succeed; so the two great industries are mutually indebted to one another.

Since 1919, Gulf has played a tremendous part in adding to the giant sulphur output of the United States, and ranks foremost today in potential production. With its reserves of many millions of tons, Big Hill, Matagorda County, Texas, will continue for years to be one of the dominating factors in the sulphur industry of the world.

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PINE PRAIRIE SALT DOME

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ABSTRACT

The Pine Prairie salt dome is a characteristic Gulf Coast salt dome, and is composed of a steep-sided, relatively flat-topped, pluglike salt core surmounted by a thimble-like cap of limestone and gypsum-anhydrite. The salt core is 1 mile in diameter and rises to within 520 feet of the surface. The limestone of the cap is exposed at the surface. The salt core and cap have been intruded into beds of Oligocene to Pliocene age. Commercial production has never been established. Four small producers were completed at a depth of about 1,300 feet on the west edge of the dome. Three later well located deep tests respectively on the northeast, southeast, and southwest sides of the dome were dry.

INTRODUCTION

Location.—The Pine Prairie salt dome is the northernmost of the Coastal group of Louisiana salt domes. It is in the southern central part of the state, in secs. 35 and 36, T. 3 S., R. I. W., 1 mile ($1\frac{1}{2}$ km.) west of Easton, a small lumber village in the center of Evangeline Parish. It is about 7 miles southwest of the village of Bayou Chicot, in what was formerly the northwest part of St. Landry Parish. It is reached by various lines to Alexandria, or by the Gulf Coast Lines to Eunice, and from either place by the Alexandria-Eunice branch of the Rock Island Railroad to Easton. Except in very wet periods, it can be reached readily by auto from either Alexandria or Lake Charles via the Pelican Highway to Oakdale, east across country to Pine Prairie village, and then south to the salt dome.

History.—The outcrop of the limestone on the southwest side of the salt dome was known to the early settlers; before the Civil War considerable lime was burned in rude kilns, the remains of which are still visible a little north of the saw mill and not far from the main quarry. About 1908, the dome was prospected by the Myles Mineral Company for limestone and salt, but no development was started.

[1] Chief geologist, Rycade Oil Corp., Houston, Tex. Published by permission of the Rycade Oil Corp.

Harris is reported to have noticed that when heated the limestone from the lower quarry gave off a petroleum odor, and to have advised exploration for oil. The exploration was started in 1909, but the first wells were unsuccessful. In 1912, the Myles Mineral Company's Number 8, on the west side of the dome, came in flowing at an estimated rate of 1,000 barrels per day. Although the well quickly sanded up, its completion started a mild boom, and some seventeen wells were drilled in the following three years. Two of these wells were completed as small producers. None of the tests were deep. From 1915 to 1920, there was desultory drilling of shallow tests without success. In 1921, the Amerada Petroleum Corporation and the Louisiana Oil and Refining Company (Invincible Oil Corporation), in a joint test, drilled a deep dry hole on the northeast flank, and Duke *et al.* drilled a deep dry hole on the southwest flank. In the following year, the Louisiana Oil and Refining Company drilled a well into the southeast edge of the cap, and a deep dry hole a little farther southeast. At the present time there is no commercial production.

PHYSIOGRAPHY

Regional physiography.—The physiographic province in which the salt domes of Louisiana and Texas occur is the Gulf Coastal Plain. In southern Louisiana, and southeast Texas, this plain is composed of the Coastal Prairie, the Kisatchie Cuesta, other cuestas farther inland, and the Mississippi Valley and Delta (Fig. 1).

The Coastal Prairie is an almost featureless plain extending from the Gulf Coast about 80 miles inland. At its gulfward margin, it is characterized by extensive marshes, especially in Louisiana and the adjacent portion of Texas, and is broken by numerous broad, shallow bays. At its inland margin, the coastal marshy belt grades into a wide belt of prairie which comprises the main part of the Coastal Prairie, and which is practically treeless except along the streams and at its inland margin.

The Coastal Prairie is in extreme physiographic youth. Along the streams and their tributaries, in general, there is considerable dissection. The interstream areas are broad and show no well-defined drainage. The amount of the dissection increases inland, and near the inland margin, the topography locally is in late youth. The only

relief which the Coastal Prairie has beyond that due to the erosion consists of:

1. Salt-dome mounds; mounds resulting from the upwarping of the prairie and rising to a maximum height of 200 feet above the general prairie level.

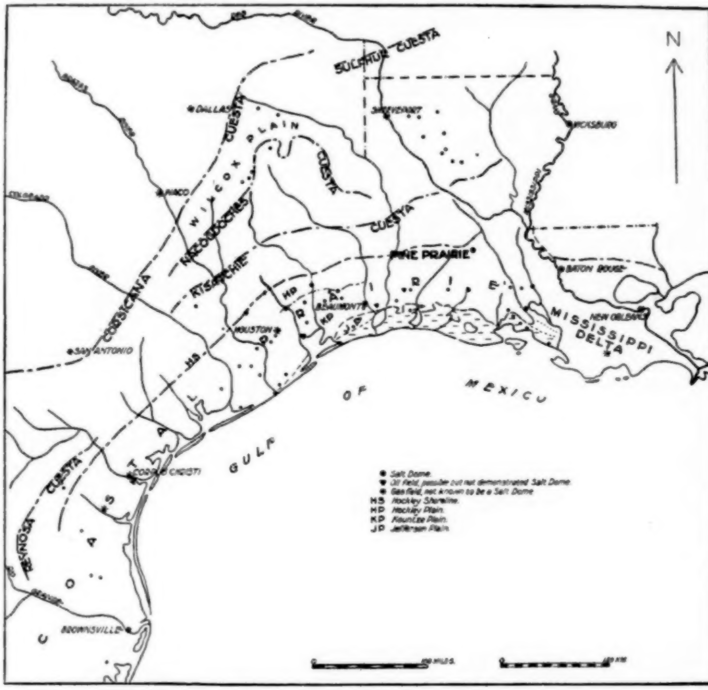

FIG. 1.—Physiographic map of the Texas-Louisiana salt-dome area. (In part after Deussen, Dumble, and Veatch.)

2. "Pimple" mounds and "blowout" holes; small, circular, sandy mounds with diameters of 20–30 feet (6–9 m.), and a rise of 1–4 feet (0.3–1.3 m.); and shallow, circular ponds of somewhat larger diameter. Contrary to the common lay opinion, they have no connection with oil, gas, or salt domes.
3. Prairie ridges; broad, low ridges extending for miles across the prairie.
4. Natural levees; in some cases abandoned.
5. Beach ridges; especially in the marshy prairie along the coast.

The Coastal Prairie is divided into several plains, marked at their landward edges by scarps, and is bounded at its inner margin by the Hockley shore line. In Louisiana and farther east, four terraces have been recognized: in order of decreasing age, the St. Elmo, the Port Hickey, the Hammond, and the Pensacola.[1] The St. Elmo terrace, apparently contemporaneous with the crystalline gravel at Natchez, but older than the great loess deposits of the east side of the Mississippi, is regarded by Matson as sub-Aftonion in age. As the Port Hickey terrace is apparently younger than the principal loess deposits of the east side of the Mississippi, the St. Elmo terrace would be pre-Iowan in age, and the Port Hickey terrace of post-Iowan age. The latter terrace is covered by a loesslike silt that may be of Wisconsin age, and in that case would itself be of Wisconsin age. The lower terraces are younger than the Wisconsin drift.

In southeast Texas, there are at least three plains: the Hockley Plain, with its inner margin well marked by the Hockley shore line through the Hockley salt dome; the Kountze Plain, which is especially well developed near Kountze; and the Jefferson Plain, which is best developed in southern Jefferson County. The Hockley Plain lies between elevations of 110–50 feet (33–45 m.) in Hardin County, and 125–75 feet (37–52 m.) in western Harris County. The Kountze Plain lies between elevations of 25–80 feet (8–25 m.) in Jefferson and Hardin counties, and between 30–90 feet (9–27 m.) in Harris and Galveston counties, and in the latter two counties, it extends nearly to the coast. The Jefferson Plain has an elevation of less than 15 feet (5 m.). The Hockley shore line is a rise of 40 feet (12 m.) in 1 mile, which contrasts strongly with the very uniform slope of the Coastal Prairie of 3 feet (1 m.) to the mile. This shore line crosses the Dallas-Beaumont branch of the Southern Pacific Lines just south of Seneca, the Houston, East, and West Texas division of the Southern Pacific lines just north of Wescott, and the Houston-Palestine division of the International and Great Northern Railroad just south of Conroe.

The Kountze shore line between the Hockley and Kountze plains is most conspicuous between Kountze and Saratoga in Hardin

[1] G. C. Matson, U. S. G. S. Prof. Paper 98-L (1916), pp. 189–90.

County, and is recognizable but indistinct in Harris County, southwestward from Humble.

The Jefferson shore line between the Kountze and Jefferson plains crosses the center of Jefferson County, near the western edge of the county, bends southwestward, and in Galveston County is only some 10 miles back from the coast. As the Loxley Plain, the youngest of the Pliocene plains, is represented on the east border of Texas, according to Matson, by the top of hills that rise 180–220 feet (56–68 m.) above sea-level, the Hockley shore line is the equivalent of the scarp which marks the seaward edge of the Loxley Plain, and the Hockley Plain is the equivalent of the next lower plain, the St. Elmo Plain. The Jefferson Plain may be the equivalent of the Pensacola Plain, and the Kountze Plain may be the equivalent of the Port Hickey and Hammond plains, but the data for exact correlation are not at hand.

In the area around the Pine Prairie salt dome, there is a broad upland level with an elevation above sea-level of 95–110 feet (29–33 m.), and a bottom land with an elevation of 50–60 feet (15–18 m.) above sea-level. The area has suffered much more erosion than the prairie nearer the coast. Only remnants of the upland level are left in the area around the Pine Prairie dome. The general region is flatly rolling with fairly broad bottom lands along the streams. By comparison of the elevation and position of this area with Matson's profiles, the upland level seems perhaps to be a part of the Port Hickey (Pleistocene) terrace, and the bottom lands to correspond to the Hammond terrace. To the south of the Pine Prairie dome, most of the prairie is open, but in the immediate vicinity, and to the north of the dome, most of the prairie is wooded.

Physiography of the dome.—The characteristic American salt dome consists of: (1) a circular pluglike core of rock salt; (2) beds dipping quaquaversally away from the salt core; and in some cases(3) a cap of rock mantling the top of the salt core; and (4) a topographic mound above the salt core. The salt-dome mound tends to have the general shape of an inverted tin wash-basin with or without a central depression.

The Pine Prairie salt-dome mound (Fig. 2) is a subcircular horseshoe-shaped mound roughly 6,000 feet (1.8 km.) in diameter and

rising 60–75 feet (18–23 m.) above the general level of the bottom lands which surround it on the south, west, and north. Mapping carried well out from the dome shows, however, that these surrounding lands standing at levels of 60–70 feet (18–21 m.) above sea-level

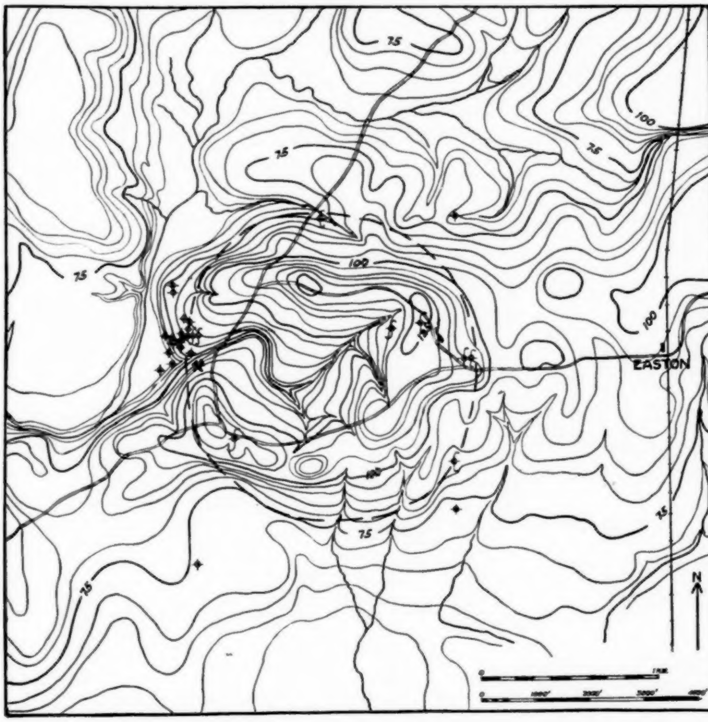

FIG. 2.—Topographic map of the Pine Prairie salt dome. (By Amerada Pet. Corp., Van K. Baker—topographer; topography slightly redrawn by D. C. Barton—datum mean sea-level; contour interval, 5 feet.)

are merely the bottom lands of Nez Pique Bayou and Caney Branch, and that there is also the upland standing at a level of 75–110 feet (23–33 m.) above sea-level. The rise of the mound above this upland level, which seems to be the correct measure of the salt-dome mound proper, is 15–20 feet (5–6 m.).

Although the central basin may be entirely erosional in origin, it is more probably a central depression of the type characteristic of the "central depression type" of salt-dome mounds. The basin has somewhat the shape of a shallow wash-basin with gently sloping, graded sides and a broad, flat, central floor. The west rim is breached by a small brook which heads on the inside of the east rim. This brook flows in a V-shaped brook valley, a few feet deep, and 10–20 feet wide. The brook seems incompetent to have carved such a basin, but there is a bare possibility that the basin is the result of a former period of erosion, so ancient that the sandy hill-slopes have had a chance to become completely graded, and that recent rejuvenation has resulted in the erosion of the modern brook valleys.

In general plan, the Pine Prairie mound seems to be similar to the Blue Ridge mound.

GEOLOGY

Surface.—The surface beds of this general region are sands and sandy clays which belong to that Pleistocene belt of sands which lies inland from the more clayey Beaumont clay to the south, and overlaps the Citronelle formation to the north (Fig. 3). This belt has been included by some writers in the Lafayette, together with much of the underlying Citronelle formation. This belt in Texas was placed by Deussen in the Lissie together with much of the Citronelle Formation; and by Hayes and Kennedy and by Fenneman it was correlated with McGee's Columbia formation, to which the Lissie is now more or less restricted.

The surface beds on the Pine Prairie salt dome consist of sands and sandy clays, and of limestones piercing the sands and clays. Lithologically, the sands and clays on the dome show no marked differences from those of the surrounding region, except possibly in being very slightly more sandy. But as transitions from belts of sandy soil to those of sandy clay are not uncommon, the apparently greater sandiness of the mound is not necessarily of significance.

Limestone is exposed at two points in the southwest quadrant of the dome. One exposure is in a small pit on the north side of the road and some 500 feet (160 m.) east of the mill. This exposure consists of a little rotten limestone and a few small bowlders of sounder limestone. The other exposure is about 1,200 feet (400 m.) north of the

mill on the west side of the road, and just south of the bridge over the brook. On only three other coastal domes, Falfurrias, Damon Mound, and Hockley, is solid rock exposed at the surface.

The area in which the limestone comes near the surface is essen-

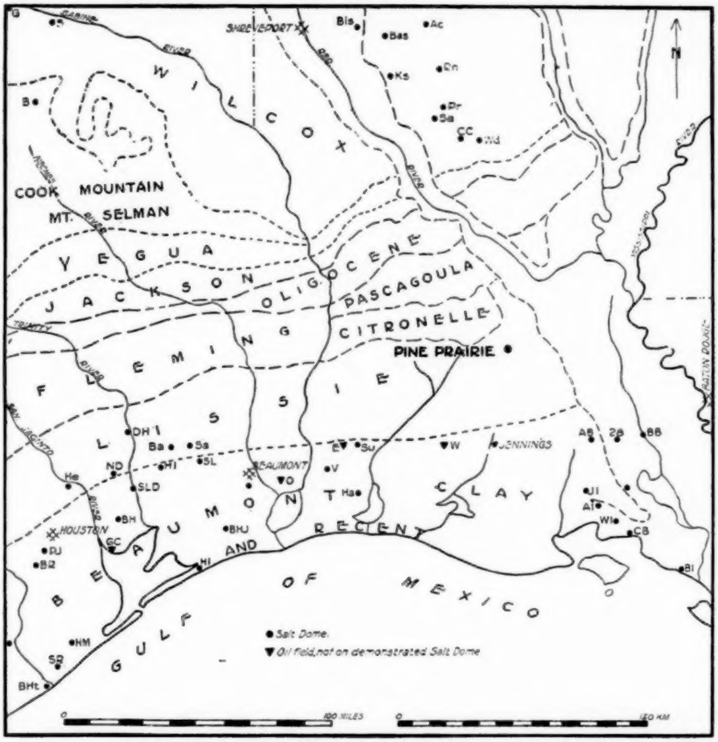

FIG. 3.—Geologic map of Louisiana and East Texas. (Largely after Deussen, Dumble, Harris, Matson, and Veatch.)

tially that of the southwest quadrant of the dome. On the hill that forms the rim in that quadrant, on the south end of the hill to the north, and the southwest portion of the central depression, the limestone is reported to have been encountered by shallow tests at depths of 20–50 feet (6–16 m.). Elsewhere over the dome, the limestone lies at greater depths.

The thickness of the limestone is shown by wells to be 200–400 feet (160–320 m.). From the well logs it is not quite certain whether or not the limestone exposed at the surface is continuous with the main cap rock or is an upper lense.

Banding shown by the limestone of the lower quarry has dips of 25–30 degrees to the southwest. As the blocks on which the dips have to be taken are not firmly in place, these dip readings are only approximate. Diamond-drill cores of cap rock from a test near the mill on the crest of the hill in the southwest quadrant are said to have shown dips of 30°. Although the limestone exposed in the upper quarry is very doubtfully in place, the banding seems also to show a southwesterly dip.

Subsurface.—The wells drilled show the presence below the surface of a characteristic salt dome, composed of a pluglike central core of rock salt capped by a thimble-like mass of cap rock.

The cap rock is flat topped and has steep sides (Fig. 4). On the top of the dome, Myles Mineral Company's wells Nos. 1, 2, and 3 went into the salt respectively at 405 feet ($122\frac{1}{2}$ m.), 405 feet, and 420 feet ($127\frac{1}{2}$ m.) below sea-level, and 520 feet ($157\frac{1}{2}$ m.), 516 feet ($156\frac{1}{2}$ m.), 520 feet ($157\frac{1}{2}$ m.) below the surface. The location of these wells was as follows: No. 1 about 1,000 feet (300 m.) in from the southeast edge of the salt table; No. 2 on the west edge of the salt table; No. 3 in the center of the northeast quadrant of the dome, about 1,500 feet (450 m.) in from the edge of the salt table. The dip of the flank of the salt core is known directly only on the west. There the Myles Mineral Company's No. 6, which was 50 feet (16 m.) west of No. 2, went into salt at 685 feet ($207\frac{1}{2}$ m.) below sea-level, or 265 feet (80 m.) deeper; and well No. 8, 80 feet (24 m.) west of No. 6, went to 1,135 feet (343 m.) below sea-level without encountering salt. On the northeast, southeast, and southwest, wells drilled to 3,879 feet (1,175 m.), 4,100 feet (1,240 m.), 4,384 feet (1,328 m.) below the surface, respectively, show that to depths of around 4,000 feet (1,200 m.) the mean slope of the edge of the salt is greater than $4\frac{1}{2}$ in 1.

The salt core is approximately circular in plan (Fig. 5). It is delimited by the previously mentioned wells, and by Price's Crowell and Spencer well at NW. cor. Sec. 36, the two Price wells at the cen-

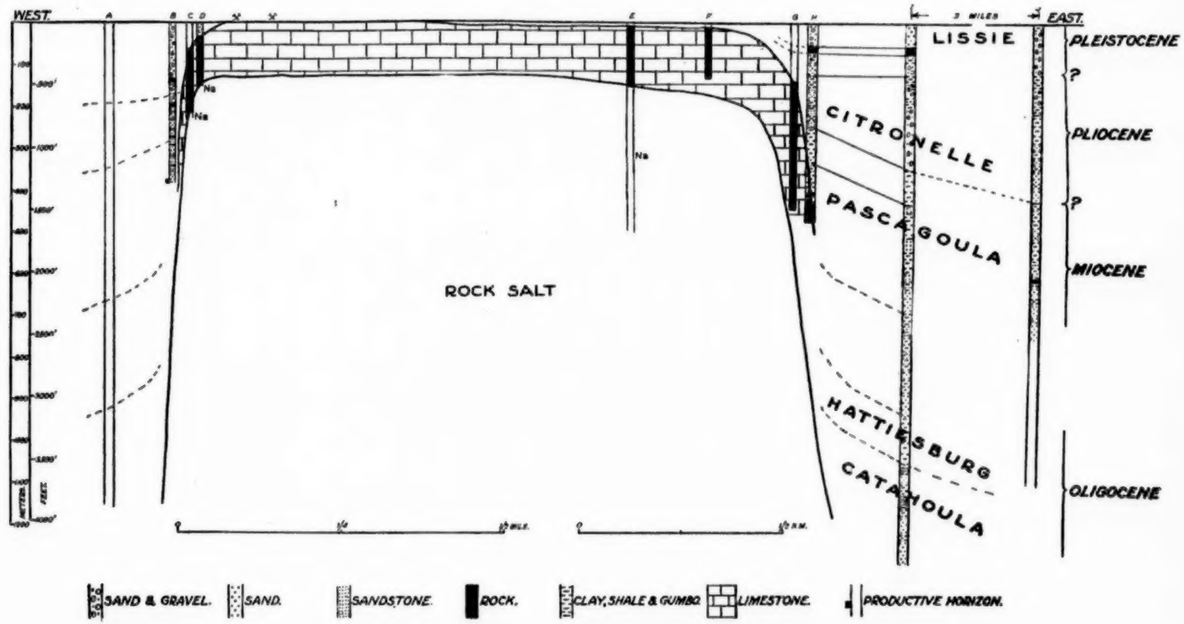

FIG. 4.—West-east cross-section across the Pine Prairie salt dome
Vertical scale = Horizontal scale

A = Duke *et al.*'s Le Danois No. 1
B = Myle's Mineral Co.'s No. 8
C = M. M. Co.'s No. 6
D = M. M. Co.'s No. 2
E = M. M. Co.'s No. 3
F = M. M. Co.'s No. 0
G = Price-Cannon's Guillory No. 1
H = La. O. & R. Co's–Vidrine No. 1
I = La. O. & R. Co.'s Gournay No. 1
J = Pine Prairie Realty Co's No. 1 (3 mi. N.-NE. of the dome)

ter of Sec. 36, and the Louisiana Oil and Refining Company's Vidrine well in the SE. cor. SW. ¼ of Sec. 36, all of which had cap rock at depths of over 1,000 feet (300 m.).

The cap seems to be a thimble-like mass of limestone and gyp-

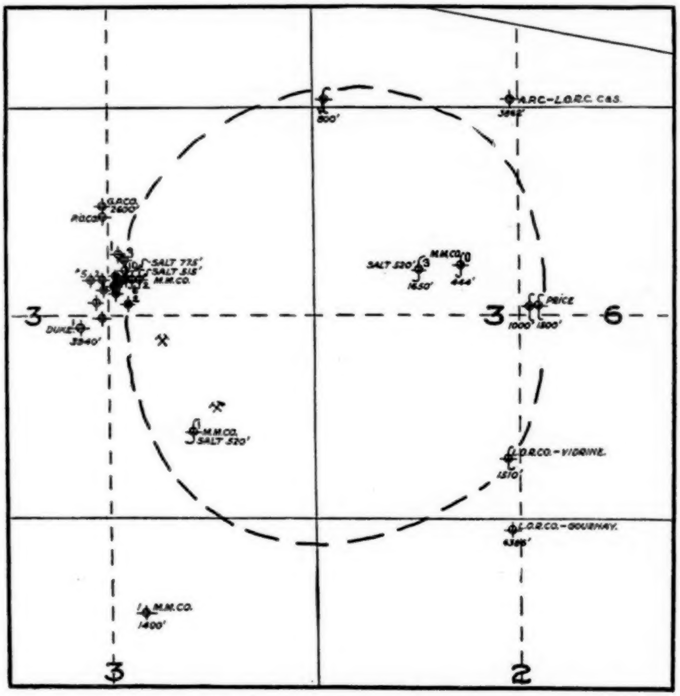

FIG. 5.—Index map to wells at Pine Prairie salt dome

sum (anhydrite?) mantling the salt core. The limestone of the cap, or perhaps of an upper lense of the cap, comes to the surface in the southwest quadrant of the dome. Seven hundred feet south of the upper quarry, the Myles Mineral Company's No. 1 encountered the cap at a depth of 115 feet (35 m.) below sea-level. On the west edge of the dome, the same company's No. 2 encountered it at a depth of 30 feet (9 m.) below sea-level. In the middle of the northeast quad-

rant, the same company's Nos. 0 and 3 encountered it slightly below sea-level. On the north edge of the dome, Price's Crowell and Spencer No. 1, was abandoned in it at a depth of 730 feet (221 m.) below sea-level. The depth of the top of the cap, however, is not available. On the east edge of the dome, Price's two wells encountered the cap at a depth of around 325 feet (100 m.) below sea-level; one of them was abandoned at around 900 feet (275 m.) and the other at around 1,400 feet (420 m.) below sea-level. On the southeast edge of the dome, the Louisiana Oil and Refining Company's Vidrine No. 1 encountered the cap at 1,380 feet (418 m.), and was abandoned in it at 1,510 feet ($457\frac{1}{2}$ m.) below sea-level.

The thickness of the cap on top of the dome is 200–400 feet (160–320 m.). In some of the edge wells it has an apparent thickness up to 1,000 feet (350 m.). This great apparent thickness is probably due to the fact that the limestone is dipping at a high angle.

The cap rock is composed of limestone and gypsum (anhydrite?), the relative proportion between the two being indeterminable. The cap exposed at the surface is limestone, and the impression gained from the accounts of the Myles Mineral Company wells is that the rock penetrated by them was mostly limestone. Some definite gypsum was encountered in them, and from the account of Mr. P. K. Kelly, of the Union Sulphur Company, the rock in the Price well on the east flank of the dome was entirely gypsum (anhydrite?). Sulphur-bearing rock was encountered in the Myles Mineral Company's wells Nos. 1 and 2. In a fishing job on the latter well, nearly a gallon of pure sulphur was brought up, some of it in lumps of pure sulphur half the size of a hen's egg and the rest of it in lumps of half-sulphur and half-limestone and gypsum.

Surrounding the salt core and the cap are sediments that probably dip quaquaversally away from the salt core and the cap. But the wells of which accurate logs are available are so scattered, and lithologic correlation between wells at a distance is so uncertain, that it is impossible to determine the dip at Pine Prairie, or to contour any horizon.

Stratigraphy.—The normal stratigraphic section for this area as determined from a study of these formations to the north is as follows:

STRATIGRAPHIC SECTION IN VICINITY OF THE PINE PRAIRIE SALT DOME

Pleistocene			
Lissie	Sand and gravel	0–200 feet	(0– 60 m.)
(Unconformity)			
Pliocene*	Non-marine	50–400 feet	(15–120 m.)
Citron formation	Yellow and red sands and clays	50–400 feet	(15–120 m.)
(Unconformity)	Gray where unweathered		
Miocene*	Marine in part, blue-green and gray clays locally calcareous	250–450 feet	(80–140 m.)
Pascagoula clay	Some layers of sand		
(Unconformity)			
Oligocene*			
Hattiesburg clay	Non-marine, blue and gray clay, some beds calcareous, thin beds of sand and sandstone	300–350 feet	(20–105 m.)
Catahoula sandstone	Non-marine gray sands, sandstones, fine conglomerates, clays	600–800 feet	(180–240 m.)
Eocene†			
Jackson	Marine gray sands and dark calcareous clays	100– 60 feet	(30– 50 m.)
Yegua	Palustrine, gypsiferous sands and clays with lignite	400–800 feet	(120–240 m.)
Nacogdoches / Cook Mountain / Mount Selman	Marine, green sands, glauconitic sands, sandstones and clays, green, black and yellow clays, brown and yellow sand	700–800 feet	(210– 40 m.)

* After G. C. Matson, U. S G. S. *Prof. Paper 98 L* (1916), p. 172.

† After E. T. Dumble, "Geology of East Texas," *Univ. of Texas Bull. No. 1869* (1920), Chap V.

The actual stratigraphic section at and around the Pine Prairie dome is poorly known. A Fleming Miocene fauna is reported by Kennedy[1] to have been obtained from a depth of 1,545 feet (468 m.) in the Pine Prairie Realty Company's well. In the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1, "re-worked Cretaceous" (Miocene) was encountered from 1,272–986 feet (385–602 m.)[2] From 1,986 feet (602 m.) to the bottom of the hole, 3,879 feet (1,115 m.), there were no megascopic or microscopic fossils, and the micro-lithology did not allow a determination of the formations. On the basis of lithology, the upper 600 feet of the Pine Prairie Realty Company's well, and the upper 400 feet of the section in the wells immediately around the Pine Prairie dome, seem to be Citronelle and Lissie, and the zone of sand and rock, 3,600–900 feet in the Louisiana Oil and Refining Company's Gournay No. 1, and 3,500 feet in the Amerada Petroleum Corporation and Louisiana Oil and Refining Company's Crowell Spencer No. 1, seem to be Catahoula, but as part of the Oligocene is fairly fossiliferous, the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1, abandoned at 3,879 feet (1,175 m.), seem not to have gone very far into the Oligocene. According to the conventional section based on the study of the surface outcrops, a well 4,000 feet deep at Pine Prairie should be well into or through the Cook Mountain formation. From our knowledge from other salt domes, the formations at a depth of 3,000–4,000 feet in the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1 should be 2,000 feet above their normal stratigraphic position. The actual stratigraphic section at Pine Prairie shows, therefore, an enormous thickening of the Miocene-Pliocene over the thicknesses given in the conventional section.

ORIGIN OF THE DOME

A study of the literature on the German salt domes shows that they have been proved to be the result of plastic deformation and

[1] W. Kennedy, *Bull. S. A. Pet. Geol.* (1917), p. 37.

[2] Determined by Miss Ellisor, geology department, Humble Oil. and Refining Company.

upthrust of the Zechstein sedimentary salt series. It is evident, also, that certain of the German domes are very similar to the American domes, and therefore it is probable that the American domes have been formed similarly. The sections available for the American domes show clearly that the salt has been intruded as an upthrust plug. The bare profile of the Pine Prairie salt core against the surrounding sediments is, of course, in itself suggestive of its intrusive character, but on account of the slight correlation that is possible, the upthrust of the lateral beds is only vaguely indicated.

AGE OF THE DOME

The salt must be older than Oligocene if it is an intruded portion of sedimentary salt series, as the salt cuts what seems to be the Catahoula sandstone. The date of the beginning of the upthrust of the salt is not determinable at Pine Prairie. At Damon Mound, an angular unconformity of some 15° between the Oligocene and the Miocene beds of the flank indicate that there had been marked upthrust of the Damon Mound salt core during or at the end of Oligocene times. Although it can be shown definitely that some of the domes have experienced little or no upthrust since early Pleistocene times, and others have experienced upthrust in very recent times, it is probable that most of the salt domes were started by the same pulse in the tectonic situation. It is likely, therefore, that the upthrust of the Pine Prairie salt core had started by Oligocene times. The presence of the salt-dome mound rising as a deformation form above a late Pleistocene surface indicates that the latest movement took place in or since late Pleistocene times.

ORIGIN OF THE CAP ROCK

Three major theories for the origin of the cap rock of salt domes have been proposed: (1) It is reconsolidated, residual material left behind in the solution of the top of the salt. (2) It is rock that was caught and pushed ahead of the rising salt column. (3) It was formed by reactions between the circulating waters of the country rock and the salt-dome waters.

In the light of the present knowledge of the cap at Pine Prairie, no one of these theories gives a very plausible theory of its origin.

The first theory is plausible in connection with the gypsum cap of the German domes, but seems inapplicable in this case; the $CaCO_3$ content of the rock salt of all domes, as far as known, is practically nil, and there is no known indication of the alteration of the limestone from gypsum. The apparent thimble-like form of the cap at Pine Prairie is more what would be expected if the cap were a secondary deposit rather than an uplifted block. Secondary deposition of lime is common as a cement in sandstones around the salt domes of the Gulf Coast. But if the cap were secondary, it seems impossible for it not to have included some of the sedimentary beds, especially the sandstones which originally rested against the salt. Such inclusions are not known at present. As there have been only a few wells through the cap, it is, of course, not well known. The cap may not extend down the flanks in the manner of the writer's interpretation of the situation, and the cap rock found on the flanks may be blocks broken off from the main mass and lagging along the edges of the upthrusting salt core. As a result of the study still in progress of the form and shape of the cap rocks of Gulf Coast salt domes and the relation of the cap rock to the salt core and to the surrounding sediments, the writer has come to the conclusion that in case of most of the salt domes the cap rock has been upthrust on top of the salt core into its present position, but he has come to no definite conclusion in regard to the ultimate origin of the cap rock. However, the theory of the secondary deposition does not seem so plausible to him as it formerly did.

OIL AND GAS

Indications.—The indications which led to the drilling were the presence of small, dark, asphaltic specks in the limestone of the lower quarry. Upon abrasion the limestone gives off a strong, fetid odor, and when heated it yields a strong odor of petroleum. No oil seeps, gas seeps, or paraffin dirt are known at or around the Pine Prairie dome. Gas seeps have been reported from Caney Branch, but as they are not large, or constant, they are probably marsh-gas seeps.

Exploitation.—Over thirty wells have been drilled; three of the tests went to depths below 3,000 feet (900 m.): the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1, about 1,200 feet out from the dome on the northeast

to 3,879 feet (1,175 m.); the Louisiana Oil and Refining Company's Gournay's No. 1, about 800 feet out from the dome on the southeast to 4,384 feet (1,328 m.); and Duke *et al.*'s No. 1 on the west to 4,100 feet (1,240 m.). Nine wells went into the salt or cap rock at shallow and moderate depths. Of the others, sixteen did not go below 1,300 feet (400 m.). Four wells were completed as so-called producers.

Production.—The oil that has been found thus far is within a small area on the west flank immediately adjacent to the dome. It is found in a sand 30 feet (9 m.) thick between 1,200 and 1,300 feet (370–400 m.). The sand bed is probably in the Pascagoula clay (Miocene).

Though for a short time oil was shipped from Pine Prairie, the production has never reached commercial magnitude. Myles Mineral Company's No. 8, the discovery well, came in with an initial production of one thousand barrels (139 tons) per day (estimated), but quickly sanded up. It pumped twelve to twenty barrels (1.7–28 tons) per day for about a year, and then, after standing for three years or four years, pumped six to thirty-five barrels (0.8–4.9 tons) per day for a year and a half. Wells Nos. 10 and 11 were of the same type. More recently Duke *et al.* completed a twenty-barrel (3 ton) well at a depth of 1,239 feet. The total production of the field to date has been around twenty thousand barrels (3,000 tons).

The oil is a thin, dark-brown oil with a gravity said to be around 28–32° Baumé.

ECONOMIC POSSIBILITIES OF THE DOME

The economic possibilities of the dome are:

1. Limestone for: (*a*) ballast—for railroads or roads; (*b*) lime—before the Civil War the limestone was burned for lime. It is said to have yielded a bluish lime; (*c*) building stone—it is very problematic whether the rock within available distance of the surface is of sufficiently good grade for building stone; (*d*) soda ash—Harris has suggested that the occurrence of the rather pure $CaCO_3$ in association with minable salt might make possible the commercial production of soda ash. The amount of the overburden is not definitely known but since it probably amounts at a mimimum of 30 feet (9 m.) of sand and 20–30 feet (6–9 m.) of rotten limestone, it is

probable that the overburden precludes commercial utilization of the rock.

2. Salt: The occurrence of massive rock salt at a depth of only 500 feet (160 m.) under a heavy cap of firm rock offers a favorable situation for salt-mining.

3. Sulphur: A small amount of native sulphur was found in the cap rock in two of the wells. There has been no thorough prospecting of the dome for sulphur.

4. Oil: The cap has been penetrated by a sufficient number of wells to show that commercial production will probably not be obtained from it.

On the west side, a small production of light oil can probably be obtained from around 1,200–300 feet near the dome. Better production than that which has been obtained in the past may be developed, but production of any considerable size is unlikely.

The lateral beds above 3,900 feet (1,180 m.) look unfavorable. The three deep tests, on the northeast, southeast, and the west, were carefully drilled with due attention to coring and should have picked up any oil sands if they were present. Since the Oligocene is one of the most important productive horizons on the Gulf Coast salt domes, there is a possibility for production in these beds from below 4,000 feet (1,200 m.).

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Ibid., Report of 1907, Bull. 7, (1908), p. 35, Plate XXX.
U. S. Geol. Survey Bull. 429 (1910), p. 21.
Wm. Kennedy, *Bull. S.W. Assoc. Pet. Geol.* Vol. I (1917) p. 37.
Data regarding the older history and wells is largely from H. M. Journee.

THE FIVE ISLANDS, LOUISIANA

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ABSTRACT

The Five Islands, so called, are in reality large, symmetrical hills, or rounded eminences, rising to an elevation of 100 feet or more from a flat, marshy plain in southwestern Louisiana. They are distributed at irregular intervals along a straight line which runs about northwest. They have aroused interest and published comment from scientists for more than a hundred years, and for a long time it has been generally known that these hills are underlain by immense bodies of salt and are the surface expression of recent upthrusting of salt plugs. Each of the islands is described in detail as to its geology, its record as a source of salt (several of the Islands have for years been the site of extensive salt-mining), and its possibilities for oil production. The evidence which these occurrences affords as to the origin of salt domes is analyzed. An extensive Bibliography is appended.

INTRODUCTION

The Five Islands are in reality five elevations along a line bearing S. 49° E. and running from Lake Peigneur, 10 miles west of New Iberia, to the mouth of Atchafalaya River. The lower four are either entirely surrounded by sea marsh or partly by marsh and partly by the water of embayments from the Gulf of Mexico. In order, from the northwest, they are: Jefferson Island, Avery Island, Weeks Island, Côte Blanche, and Belle Isle (Fig. 1).

Great masses of salt have been found beneath each of the islands, but only one, Belle Isle, has yielded even a trace of oil, and even here only small quantities have been found.

The islands attracted the attention of the earliest explorers in this part of the country, and numerous papers have been written concerning them (see appended Bibliography). Most of the early writings are of little scientific importance, as the descriptions were influenced by the theories of their origin advanced by the various writers, theories quite absurd in the light of present knowledge.

The papers by A. C. Veatch on "The Five Islands,"[50]* by G. D. Harris on the "Rock Salt in Louisiana"[51] and "Oil and Gas in Louisi-

*Numbers refer to papers in Bibliography.

FIG. 1.—Map showing Salt Domes in southern Louisiana

ana,"[52] by Captain A. F. Lucas on "Belle Isle,"[54] and by G. S. Rogers on the "Intrusive Origin of the Gulf Coast Salt Domes"[55] are much better than the earlier papers and have been drawn on freely in the writing of the present paper. Material has also been received from numerous other sources, including companies and individuals who have been in close touch with the exploration and exploitation of the islands. For their kind assistance special thanks are due C. J. Webre, David Donoghue, T. W. Moore, Wallace E. Pratt, of the Humble Oil and Refining Company, Donald C. Barton, of the Rycade Oil Company, Sidney Bradford, of the Avery Rock Salt Mining Company, and H. C. Fultz, of the Myles Salt Company, Ltd.

JEFFERSON ISLAND

LOCATION

Jefferson Island is on the southeast side of Lake Peigneur about 9 miles west of New Iberia, and may easily be reached from there by automobile. It is only a short distance north of Bob Acres, a station on the Abbeville branch of the Southern Pacific Railroad, which leaves the main line at New Iberia.

HISTORY

For many years this island was best known as "Côte Carline," which name was used as early as 1818 by Darby in his *Emigrant's Guide to the Western and Southwestern States.*[3] Later it was variously called Depuy's Island, Miller's Island, and Orange Island. The present name is after Joseph Jefferson, the actor, who for many years had a winter home there.

In 1894 Mr. Jefferson let a contract for drilling a well near his home, and this resulted, early in the summer of 1895, in the discovery of salt at a depth of 334 feet. Three years later, eight holes were drilled to determine the form and extent of the salt mass. Only four reached the salt, and the work was discontinued.

In July, 1919, C. J. Webre, under the management of Lawrence Jones and J. L. Bayless, of Louisville, Kentucky, drilled thirty-six holes and contoured the salt (Fig. 2). In October of the same year, these gentlemen organized the Jefferson Island Salt Mining Company and began sinking a shaft, which, however, was lost at the top of the salt. During the month of March, in the following year, another shaft was started, but owing to difficulties in sealing off the water, it was not completed until February, 1922. Some time was required to cut out a working space of sufficient size to permit operations on the scale contemplated by the management, and regular production was not under way until April, 1923. Since then production has been continuous.

PHYSIOGRAPHY

In reality Jefferson Island is not an island, since it rises from a nearly dry plain, but it is called an island because of its general resemblance to the other members of the Five Island group. The area of the island is about 300 acres. It rises to a maximum elevation of

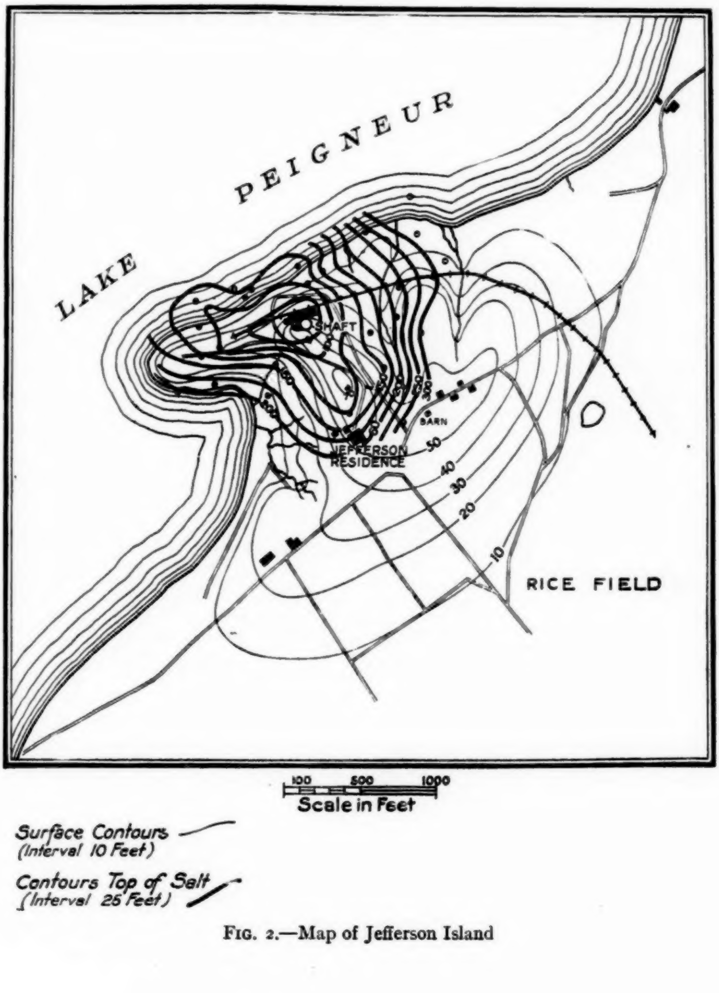


FIG. 2.—Map of Jefferson Island

75 feet above the plains and is of rather smooth contour, with the exception of a wave-formed bluff, 30 feet in height, which faces Lake Peigneur to the north. This lake is about 2 miles long, and its depth is variously estimated from 15 to 30 feet. The plains surrounding the island are low, and since they are easily flooded, they are used for the cultivation of rice.

GEOLOGY

Surface.—In the bluff on the north side of the island the section shown in Table I is exposed.[51] This is the only place on the island where gravel is exposed, clay and surface soil being found elswhere.

TABLE I

SECTION ON NORTH SIDE OF JEFFERSON ISLAND

	Feet
Surface soil, yellow clay darkened by organic matter....	2
Light yellow clay with limestone concretions...........	26
Gravel..	2

Subsurface.—In the course of operations in connection with the exploitation of the salt stock, it was found that the overlying strata are predominately sand and gravel, with less important beds of blue clay. All are so lenticular as to mask any arching due to the upthrust of the salt. Cap rock was found in only a few holes and consists of 18 to 24 inches of porous gray limestone. Three holes failed to encounter salt, although drilled somewhat deeper than those that did, the deepest reaching a depth of 475 feet below sea-level. The strata penetrated are essentially of the same character as those overlying the salt.

Through the exploration work by drilling, carried on during the year 1919, the form of the uppermost part of the salt stock was determined to be as shown on the accompanying map. Judging from the general contour of the portion which has been mapped, it seems that the salt core probably extends some distance beneath the lake to the north.

PALEONTOLOGY

A number of fossils were found in the railroad cut on the north slope of the island, and these have been identified by W. C. Mansfield, of the U. S. Geological Survey, and W. B. Marshall, of the U. S. National Museum, as follows:

Vivipara subpurpurea Say?

Pleurocora near *P. filum* Lea

Quadrula pustulata Lea
Crenodonta hers (Say) Ortmann
Amygdalonsaias elegens (Lea) Ortmann
Rangea cuneata Gray
Erynia parva (Barnes) Ortmann
Unionidae, fragments

Of their age Mansfield says, "All the molluscan specific names of genera are represented in the Recent fauna. The horizon, as indicated by the imperfect preservation of the fauna, probably is late Pleistocene or early Recent." As these could not have been deposited in their present position, they indicate that the mound was probably formed by a very late Pleistocene or post-Pleistocene uplift.

SALT PRODUCTION

The shaft enters the salt stock almost at its highest point, which is about 40 feet below sea-level and 100 feet below the surface of the ground. The shaft, which is circular in form, with an internal diameter of 25 feet, is walled with concrete and reaches a depth of about 900 feet. It is divided into four compartments, and the salt is hoisted by an Allis-Chalmers balanced hoist with skips of 5 tons capacity.

Mining is carried on by an adaption of the shrinkage system. A large undercut is made by drilling and blasting, the salt being loaded into cars by hand shoveling. Then slice after slice is blasted down, the fallen salt serving as a working floor, until the desired height is reached. In this manner large chambers 40 feet wide by 80 feet high are cut. The broken salt is loaded into cars by large electric shovels and then hauled to the shaft.

The salt from the different stocks of the Five Island group varies somewhat in physical character. That at Jefferson Island is particularly firm and shows very little tendency to shatter when struck with a hammer. It is also rather free of impurities and is on the whole of lighter color than the salt from the other islands.

AVERY ISLAND

LOCATION

Avery Island is about 10 miles southwest of New Iberia and 3 miles from the shores of Vermilion Bay. It was originally isolated by the surrounding marshes. However, as early as 1818 a raised dirt road or causeway had been built from the northernmost point of the

island to the mainland.[3] Communication by water was greatly hindered by a bar at the mouth of Petite Anse Bayou. This was partially overcome in 1880 by digging a canal from the lower part of the bayou across the marshes to the Gulf. In 1886 a branch of the Southern Pacific was completed from New Iberia to the island.

HISTORY

This island was until recently best known as Petite Anse. Earlier names used were Thomas' Island, Marsh's Island, and Salt Island.[4]

That the existence of brine springs here was known to the aboriginal inhabitants long before the coming of white men is shown by a great deposit of potsherds and ashes, extending over an area of approximately 5 acres and in places nearly 3 feet thick. However, this work was long abandoned, and the Indians found by the whites knew nothing of the springs.

The springs were rediscovered in 1791 by one John Hayes while hunting, and an attempt was soon made to use the water for the recovery of salt.[50] In 1812, due to the demand and increased value of salt resulting from the war, John C. Marsh, owner of the island, established quite an industry and by 1817 was supplying to a large extent the demands of the settlements of Attakapas and Opelousas.[3] However, the competition of imported salt eventually crushed the local industry, and operations ceased.

Following the opening of the Civil War, salt became very scarce, and John Marsh Avery, the eighteen-year-old son of Judge D. D. Avery, owner of the island, and grandson of John C. Marsh, who built the old salt works in 1812, reestablished the industry. The demand soon overtaxed the capacity of the springs, and it was decided that the salt wells be cleared and deepened. In the course of this work massive rock salt was found, which subsequently proved to be part of a great stock underlying the island. The date of this discovery was May 6, 1862. For nearly a year following, salt was quarried from a number of large open pits,[6-9] but on April 17, 1863, this activity was brought to an end by the destruction of the works by the Federal forces under General Banks.[8] The amount of salt taken out during this period is variously estimated between 10,000 and 30,000 tons.

No further work was done until 1867, when Chouteau and Price sunk the first shaft, 8 by 8 feet in plan, and 83 feet deep, afterward increased to 90 feet, about 58 feet being in solid salt. Galleries 8 to 10 feet high and 25 feet wide were driven east and west. In 1870 Mr. Price died and Mr. Chouteau abandoned the mine.

In 1879 the mining rights were leased to the Galveston Company, and in 1880 they were transferred to the American Salt Company, which occupied Chouteau's 90-foot shaft and fitted up a mill for crushing the salt. The salt was mined by cutting chambers and cross-headings averaging about 40 feet wide and 25 or more feet high, pillars 40 feet in diameter being left to support the roof.

To secure transportation, a canal was cut across the marshes from a point near the mouth of Petite Anse Bayou to the Gulf. A tramway was built from the mine, and a short embankment was made across the marsh to Petite Anse Bayou, where a number of slips were dug. The salt was loaded into lighters and carried down the bayou to Vermilion Bay, where it was transferred to schooners. This did not prove very satisfactory because of the cost of transfers and because the lighters and schooners frequently ran aground on the mud-flats and bars.

In 1886 the American Salt Company was succeeded by the New Iberia Salt Company, which made arrangements with the Southern Pacific Railroad for a branch line from New Iberia. This was completed in 1886 and solved the question of transportation.

The extreme irregularity of the surface of the salt was not fully appreciated by the companies first engaged in its mining. The galleries on the 90-foot level were driven under the false belief that there was a thickness of 40 or 50 feet of salt above them, and they soon approached the outer limit of the salt. Water commenced to come into the mine through the crevices and, once started, but little time was required for it to dissolve the salt and form larger holes. Thus the first sink hole was formed as early as 1883. Others soon developed, and the sand, water, and débris carried into the mine greatly interfered with mining operations. First the eastern and then the western side of the mine was abandoned, and finally (1885) it was decided that the shaft be sunk 70 feet deeper. This additional depth, with the 8 feet required for the pump, made the total depth of the working shaft 168 feet. Work was prosecuted on the 160-foot level by driving galleries and crossways 80 feet wide and 40 feet high and leaving supporting pillars 60 feet in diameter.

On July 1, 1893, Myles and Company, of New Orleans, obtained a sublease on the property. The water which entered the upper levels through the sink holes finally effected an entrance to the lower levels and caused that part of the mine to be abandoned in July, 1895. Operations were continued in the upper level till 1896, when the mines reverted to the Avery family by default of contract.

In 1898 the Avery-Rock Salt Mining Company was organized to carry on operations in the old mine and to sink a new shaft. Borings were made and a site was selected southwest of the old mine and beyond the limits of the old workings. After considerable trouble with water-bearing sands and gravels, the salt stock was entered at a depth of 54 feet. Profiting by the history of trouble with water breaking in, the new management sunk the shaft to a depth of 518 feet, thus getting well within the salt body. The shaft was completed in 1899 and is still in use. In the summer of 1922 a second shaft was sunk for ventilation.

PHYSIOGRAPHY

Avery Island is roughly oval in form, its greatest diameter, of about $1\frac{1}{2}$ miles, trending in a northwesterly direction. It is almost entirely surrounded by marsh land. On the east and southeast there is

a large cypress swamp. The western side is skirted by Petite Anse Bayou, branches of which run along the northern and southern sides and finally lose themselves in the marsh (Fig. 3).

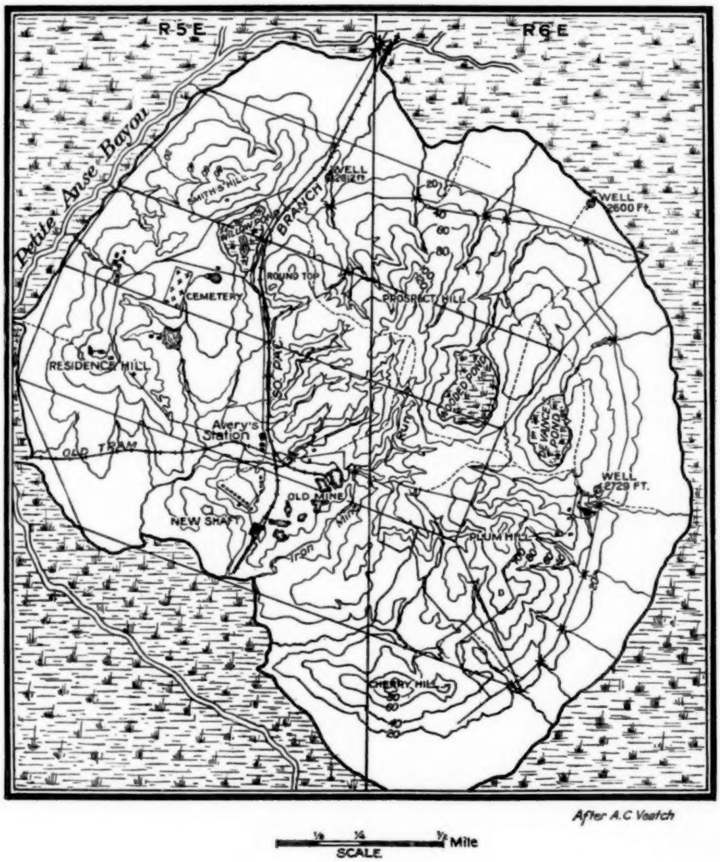


Fig. 3.—Map of Avery Island

The maximum height is 152 feet above the marshes. The surface is extremely uneven. Several large ponds are present, some of which appear to be sink holes, probably formed by the removal of salt from

beneath by solution; indeed, it may be that the general rough character of the topography is due in a large part to the same action.

GEOLOGY

Surface.—Even before any considerable work by man, Avery Island presented more exposures of the materials underlying the surface than the other members of the group; with railroad cuts and the development of sink holes from mining operations, considerably more is exposed.

While the island is mostly covered with a brownish-yellow loam, there are in the southern part numerous exposures of gravel. These are best seen on Cherry Hill and at the shaft. Sand and gravel from pits along the railroad track are used for ballast along a considerable portion of the Southern Pacific line. While this sand is of fairly good quality, the best is obtained near the mouths of the ravines, where the little clay contained has been removed by water.

Sandstone outcrops along the sides of the ravine known as Iron Mine Run from the old salt mine almost to its head, where several small gullies branch off, and thence along a line running northeastward, almost to Willow Pond. As exposed, it is a fine-grained pink sandstone with scattered particles of hematite, but underground it is chocolate colored and in places it is rather coarse. The large sinkhole near the old mine extends 63 feet below the surface and affords an excellent exposure. The sediments here are almost entirely white and orange sands, with occasionally some gravel and masses of clayey sand. The true dip of the series is marked by cross-bedding, false-bedding, and landslides.

In the northern part of the island there are numerous outcrops of a variegated chocolate, yellow, and green jointed clay, the most notable occurring on the northwest slope of Prospect Hill, on the western slope of Smith's Hill, in the railroad cut northeast of Avery's Station, and on both the eastern and western slopes of Residence Hill. False-bedding and cross-bedding render dip determination practically impossible.

In one of the gullies at the head of Iron Mine Run there is exposed a bed of lignite. A shaft 30 feet deep was sunk in an attempt to mine this for local consumption, but the project was soon given

up. The bed was found to be 18 feet thick, and it is underlain by at least 85 feet of clay, as is shown by a near-by boring. The beds dip 44° SE., and strike S.21° W. A boring 220 yards farther down the gully passed through the section shown in Table II.

The sediments in this section are stratigraphically higher than the lignite, and the absence of the latter from the section, together with its dip as mentioned above, shows clearly that it dips downward against the salt.

Subsurface.—The most important underground feature is the salt stock, which is overlain and surrounded by sedimentary strata. The areal extent of the stock has not been determined. A few drill

TABLE II

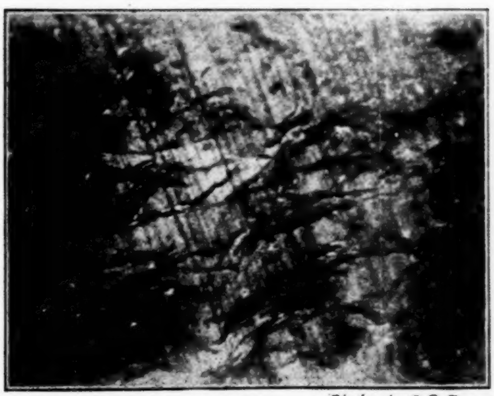
SECTION IN IRON MINE RUN, AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Fine, sandy clay soil	0–4	4
Very fine-grained, soft, pink and drab or purple sandstone	4–160	156
Hard, coarse-grained, chocolate-colored sandstone	160–66	6
White rock salt, lower limit not reached	166–1,005	839

holes were sunk in the vicinity of the mine to eliminate the possibility of extending the workings out of the salt, but none of these were off the edge of the stock. This proved a comparatively small area, but the salt is believed to underlie the greater part of the island, since it is well established that, in common with the other islands of the group, this island owes its origin to the upthrust of the stock. This stock is the highest in the Gulf Coast district, the uppermost part being a few feet above sea-level and only 17 feet below the surface. Due to unequal removal of salt by solution, it is extremely uneven, a change in elevation of 80 feet in less than 200 yards having been observed.

In a general way the salt mass resembles a schist, because of the streaked banding of light and dark salt (Figs. 4 and 5). In vertical section the streaks are seen as parallel bands, the dark being 2 to 6 inches wide, the light somewhat wider. In plan they are very irregular, twisting, folding, and forming all sorts of figures within the mass. However, near the outer margins they are more or less parallel to

A



B Photos by G. S. Rogers

FIG. 4.—Flow Structure in the Salt, Avery Island, La.

the walls. These facts, together with the elongated forms commonly exhibited by the individual salt crystals, indicate that the salt has flowed vertically, and affords rather convincing evidence that salt domes are due to intrusions of great masses of salt which are plastic under pressure.

The salt is mostly white, hard, dry, and crystalline, the individual crystals varying from $\frac{1}{8}$ to $\frac{1}{4}$ inch across and up to more than 2 inches in length. The salt stands up well, and practically all can be shipped as rock salt, differing in this respect from the salt at Weeks Island, which shatters readily. The purity of the salt, even of the darker portions, is remarkable. These darker portions, so evident as streaks or bands, are not caused by any dark substance, but by

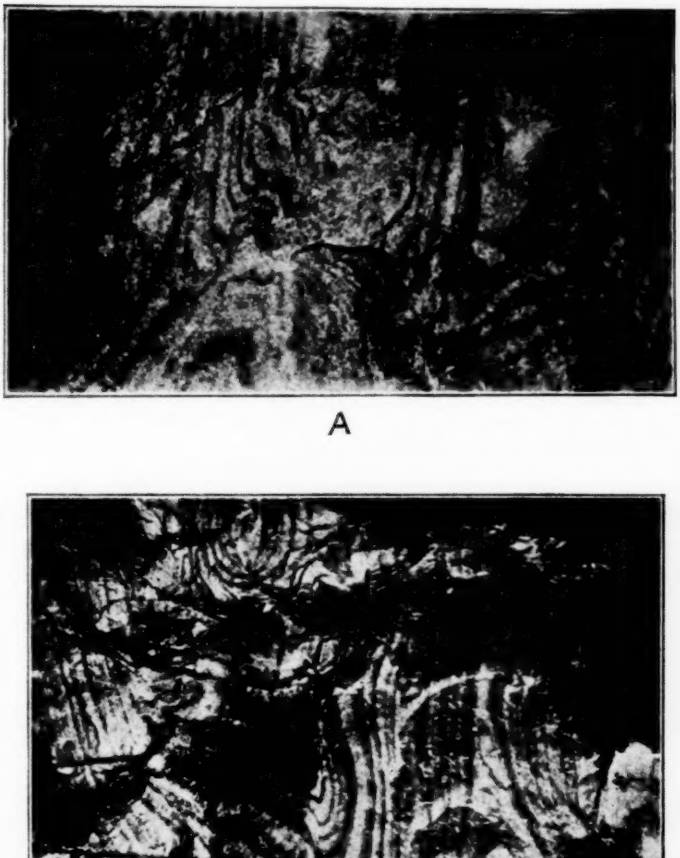
TABLE III

ANALYSES OF LIGHT AND DARK SALT FROM AVERY ISLAND

	Light Salt	Dark Salt
NaCl	99.10	96.53
H_2O	0.10	0.20
$CaSO_4$ (soluble)	0.33	1.05
$CaSO_4$ (insoluble)	0.23	2.16
	99.75	99.94

the absorption of light rays by minute particles of transparent anhydrite. This anhydrite may easily be filtered from water in which dark salt has been dissolved. Analyses of light and dark salt are given for comparison (Table III).[51] Other analyses of salt from this dome are given in Table IV.[50]

The only foreign material found within the salt core is a rather thin mass of tough red sandstone which extends vertically at least 80 feet and along its strike a distance of 75 feet.[55] It is extremely irregular in thickness, ranging up to 10 inches in some places and pinching out in others. Though tough, the rock is brecciated, the many small fissures being filled with salt. Under the microscope it is seen to consist chiefly of quartz crystals with a few fairly fresh feldspars. Some of the grains are well rounded, but others are angular. Most of the quartz grains show evidence of strain, and there has been considerable secondary growth. The cement is chiefly silica and iron oxide.



A

B

Photos by A. C. Veatch

FIG. 5.—Flow Structure in the Salt, Avery Island, La.

The cement and secondary growth of the quartz grains indicate circulation of ferruginous and siliceous waters after the sand had become placed, and such waters could not have circulated through the salt mass without dissolving much salt and introducing much foreign material. The rock must therefore have been cemented before it entered the salt mass. Also, its irregularity in thickness and vertical attitude suggest that it has been stretched out under pressure. It therefore seems to represent a fragment of sandstone picked up by the salt in its upward course, and there appears to be no way of ascertaining the formation from which it was derived. In general appearance it does not resemble any Tertiary rock in this district, but its red color suggests that it is Permian, for similar rocks are commonly found in the Permian series of the Texas Panhandle. However, such a correlation must not be too readily accepted.

TABLE IV

ANALYSES OF SALT FROM AVERY ISLAND

Chemist	NaCl	$CaSO_4$	$CaCl_2$	Mg_2Cl	$MgSO_4$	Other Matter	Not Determined
Jules Lafort	97.92	....	....	....	....	....	2.08
E. W. Hilgard	99.88	0.126	trace	....	....	....	....
Peter Colloer	98.90	0.838	0.146	0.022	....	0.080	0.014
Dr. Riddle	98.88	0.76	0.13	0.23	....	....	....
C. A. Goessman	98.88	0.79	trace	trace	....	0.33	....
C. A. Goessman	98.88	0.782	0.400	0.003	....	0.33	....
Joseph Jones	99.617	0.318	....	....	0.062	0.003	....
F. W. Taylor	98.71	1.192	trace	0.013	....	0.03	....
Dr. Doremus	99.097	0.729	....	....	0.158	0.039	....
Gustavus Bode	99.252	0.694	0.042	0.012	....	....	....

All the fossils found on the island are of Quaternary age. Since all the sediments overlying the salt in the southern part of the island seem to belong to the same series of sands and gravels as those in which these fossils were found, it appears that they are all of Quaternary age. The section passed through by the present shaft is shown in Table V. The clays found in the northern part of the island are soft, and it is believed that they also are Quaternary because of their close association with the gravels and the lack of any decided break between them.

Normally, the beds overlying a salt stock are nearly flat or rather

gently arched. It follows, then, that the attitude of the strata in Iron Mine Run, where they are seen to dip down against the salt, is certainly abnormal. This is very probably due to slumping resulting from the solution of the salt, and bears out the idea that the general rough topography of the island results from this sort of action.

TABLE V

SECTION OF SALT-MINE SHAFT, AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Surface soil	0–4	4
Yellow sand	4–16	12
Sandy clay and gravel (water line at 24 ft.)	16–24	8
Sand and gravel	24–54	30
Salt	54–	

Three wells throw some light on the character of the sediments around the salt core. The section penetrated by the well near Sugar House is given in Table VI. This well clearly marks the eastern margin of the salt, since it penetrates both salt and sediments.

TABLE VI

RECORD OF A WELL NEAR SUGAR HOUSE, AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Superficial detritus	0–330	330
Rock salt	330–2,593	2,263
Blue sand (some gas) (struck a log at 2,643 feet)	2,593–2,643	50
Blue gas sand	2,643–2,663	20
Salt	2,663–2,727	66
Bottom of hole still in salt	2,727–	

A deep well by the railroad track near the north end of the island passed through the section shown in Table VII.

Another well was drilled to a depth of 2,600 feet about $\frac{3}{4}$ mile east of the second, but nothing new was found in the section.

The sediments passed through by these three wells are similar in every particular, including the buried logs, to those now being laid down in this region, and accordingly are thought to be of Quaternary age. This conclusion is further justified by the fact that the

wood, discovered at depths of 2,643 feet and 1,400 feet, is in a much better state of preservation than would be expected from any Tertiary lignite bed.

PALEONTOLOGY

Hilgard reports finding imperfect vegetable remains, shells of *Paludina*, and several species of *Unio* and a *Cyclas* on the eastern slope of Residence Hill. Of greater interest, however, are the vertebrate remains found in the sections exposed by the sink holes between the old and new mines, where bone and pottery beds are found.

The first notice of vertebrate remains on the island, according to Veatch, was given by Professor Joseph Henry in a paper before the

TABLE VII

RECORD OF WELL IN NORTH PART OF AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Yellowish clay	0–500	500
Gravel	500–700	200
Gray sand (water stratum at 1,000 feet)	700–1,000	300
30 feet of shells, approximately	1,000–1,100	100
Gray sand (logs passed through at 1,400 feet)	1,100–1,400	300
Gray sand	1,400–2,612	1,212

Chicago Academy of Sciences, on the verbal statement of a Mr. T. F. Cleu, who contibuted a specimen of basket work to the Smithsonian Institute.[21] Dr. Richard Owen, who visited the island in 1865, mentions the occurrence of pottery, but says nothing about fossil vertebrates. In 1883 Mr. William Crooks, of the American Salt Company, presented to the Smithsonian Institute a collection of bones obtained while sinking an air shaft. These were studied by Professor Joseph Leidy, who made them the subject of a brief communication to the Philadelphia Academy of Sciences in 1884[28] and of a detailed report published in the *Transactions of the Wagner Free Institute of Scienec* in 1889.[34] In this he lists:

Mastodon americanus
Mylodon sp. cf. *robustus* Owen
Mylodon harlani Owen
Equus major De Kay

At about this time General Dudley A. Avery gave several bones to the Smithsonian Institute, and one of them was identified as the claw of a *Megalonyx*.

Probably the largest collection from this locality is that made by Dr. Joseph F. Joor in 1890 for Tulane University.[39] These were studied by Professor E. D. Cope,[40] who described two new species of *Mylodon* and expressed the belief that the teeth identified by Leidy as *Equus major*, De Kay, really represent a new species. The species recognized by him are:

Mastodon sp.
Mylodon harlani Owen
Mylodon renidens Cope
Mylodon sulcidens Cope
Equus intermedius Cope

To this list Dr. Joor adds, with some doubt, the remains of an *Elephas*. The bone bed is rich and might yield some good material to the careful worker.

On the north side of one of the sink holes resulting from water entering the old mine, bones were found buried beneath about 17 feet of sediments. The section exposed is as shown in Table VIII. Formerly about 10 feet of salt was exposed in this section below the bone beds, but this is now hidden.

According to descriptions, a fairly complete skeleton of a mastodon was unearthed in grading for the railroad embankment just south of the shaft now in use, but it was buried in the course of the work before being seen by anyone appreciating its value. A few bones which rolled to the foot of the embankment were later picked up by General Avery, and a piece of tusk about three feet in length was found by a workman.

A few scattered bones have been found in Iron Mine Run a short distance above the old mine, but no determinations are available.

SALT PRODUCTION

The shaft now in operation enters the salt a few feet above sea-level. It is 21 by 10 feet, 518 feet deep, and is divided into three compartments, two being used for hoisting, the other for compressed air for power, electric wires, and ventilation. As at Jefferson Island, the

salt is mined by undercutting, breaking down the salt, and loading into cars by electric shovels. It is then hauled to the shaft by an electric locomotive. Formerly, galleries 30 feet wide by 60 feet high were worked, leaving pillars 30 feet square. Other sizes have also been used. The galleries now being driven are from 40 to 60 feet wide and 60 feet high (Fig. 6).

Instead of using skips for hoisting the salt, the mine cars are run upon the cages and hoisted to the top floor of the mill, where they are dumped. The purity of the salt is such that no refining process is required. The salt is simply crushed, screened, ground, and winnowed to drive off the fine salt dust which has a tendency to deliquesce and cement together the larger grains.

TABLE VIII

SECTION IN SINK HOLE ON AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Gray sandy loam with pebbles	0–7	7
Broken pottery and ashes	7–8	1
Dark-gray silt	8–13.5	5.5
Fine black loam containing many grass roots	13.5–15	1.5
Medium-coarse white sand grading into gravel	15–17.5	2.5
Black to dark-brown, very hard, medium-fine gravel containing remains of vegetable matter, *Mastodon*, *Mylodon*, and *Equus* bones	17.5–19.5	2

The total production of salt from Avery Island up until January 1, 1924, was 2,578,379 tons, of which 1,866,163 tons were taken from the new shaft. The annual production for several years has been about 100,000 tons, that for 1923 having been 92,000 tons.

WEEKS ISLAND

LOCATION

Weeks Island is 15 miles south of New Iberia and is on the east side of Weeks Bay, an eastern lobe of Vermilion Bay. Before the Civil War it could be reached from the mainland only by canoe through Weeks Bayou from Prairie au Large below New Iberia. The products of the island, of which sugar was most important, were shipped by shallow-draft schooners which could enter the bay. During the war, or shortly afterward, a raised dirt-way was built to the

mainland. A road is maintained over this, and the island may be reached easily by automobile from New Iberia. A short track from the Cypremort branch of the Southern Pacific, leaving the main line at Baldwin, also goes to the island.

HISTORY

Previous publications[50] on this island have called it Grand Côte, but as it is at the present time best known as Weeks Island, it is so called in the present writing.

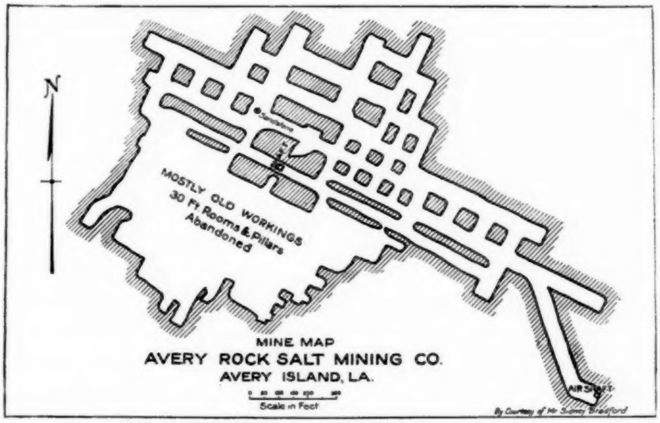


FIG. 6.—Mine Map, Avery Rock Salt Mining Co., Avery Island, La.

The discovery of salt on Avery Island in 1862, and the high price of salt at that time, caused a few wells to be dug in search for salt on Weeks Island, but without success. Following this failure no further work was done until after the discovery of salt on Jefferson Island in 1895 and on Belle Isle in 1896, when Mr. F. F. Myles undertook the exploration for salt in a more systematic way. In March, 1897, with Mr. N. Conrad in charge of the drilling, he started the first hole near the sugar house. Salt was struck in the fourth hole at a depth of 276 feet, July 25, 1897. About this time Captain A. F. Lucas, later of Spindletop fame, was put in charge. In all, fourteen holes were drilled in the preliminary examination, several of these running into the salt. In 1898 the Myles Salt Company was organized and fourteen additional holes were drilled to determine the best location to begin mining operations. A shaft was started in July, 1898, over the highest point on the salt stock. One hundred feet of sectional cast-iron tubular casing 10 feet in diameter were used in sinking to the salt. Because of trouble with water, nearly three years were required to sink the shaft into the salt and

make a perfect seal. A rectangular shaft was continued to a depth of 645 feet below the surface. Production began in March, 1902, and has been practically continuous up to the present time.

PHYSIOGRAPHY

Weeks Island is nearly circular in outline and is about 2 miles in diameter (Fig. 7). On the three sides away from the bay, which lies to the west, there is a great sea marsh. The island rises to a maximum height of 135 feet above sea-level, and the surface is very uneven, partly due to dissection and partly to slumping resulting from salt below being dissolved and carried off in solution; ponds and small lakes represent modified sink holes.

The Devil's Backbone, the principal topographic feature,occupies the central part of the island and has a general trend a little east of north. The slopes of the gullies on either side are almost vertical and from 20 to 60 feet in height.

GEOLOGY

Surface.—Nearly the whole of the island is covered with a brownish-yellow loam, but in places, notably in the sharp gullies on the east side of the Devil's Backbone, the upper stratum of clay has been cut through so as to expose underlying sands and gravels. Toward the southern part of the ridges there are ferruginous sands. These contain chert pebbles and an occasional interstratified bed of sandy gray clay. The whole mass has been so tilted that the planes of stratification dip in various directions and at different angles. Springs are common on the northern slopes of the island.

Subsurface.—The contour of the top of the portion of the salt stock underlying the western part of the island has been determined by drill holes and is shown in Figure 7. The portion in the vicinity of the shaft is shown in more detail in Figure 8. The highest point on the salt is 46 feet below sea-level. The surface of the salt core is very irregular, no doubt due to the removal of great quantities of salt by circulating water. As at Avery Island, this is indicated by the variation of dips in overlying strata which would otherwise be horizontal or only gently flexed.

The salt core is in most other aspects very much like that at Avery Island. The salt has the same remarkable purity, the same

crystalline structure, and there are the same vertical streaks, the darker being due to inclusions of anhydrite. There is, however, one notable difference: whereas the salt at Avery Island is remarkably hard, that from Weeks Island shatters readily under the blows of a hammer. There are also horizontal lines of weakness along which the

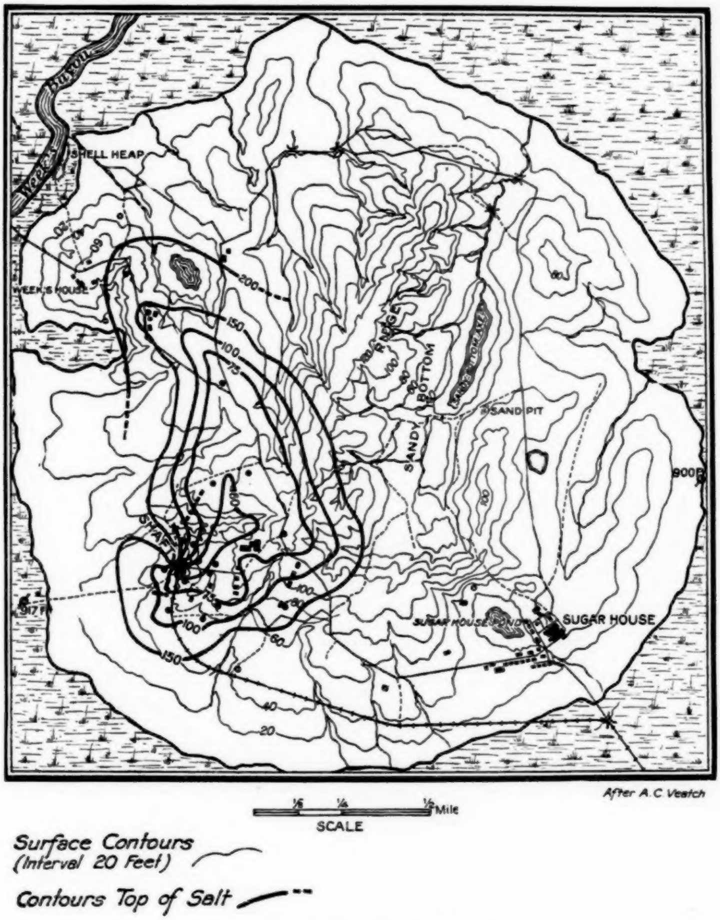


FIG. 7.—Map of Weeks Island

salt breaks as though stratified. These are thought to result from pressure. The sections revealed in exploring the salt core show little variety as to the character of the sediments overlying and surrounding the stock. There is commonly a surface layer of clay from a few

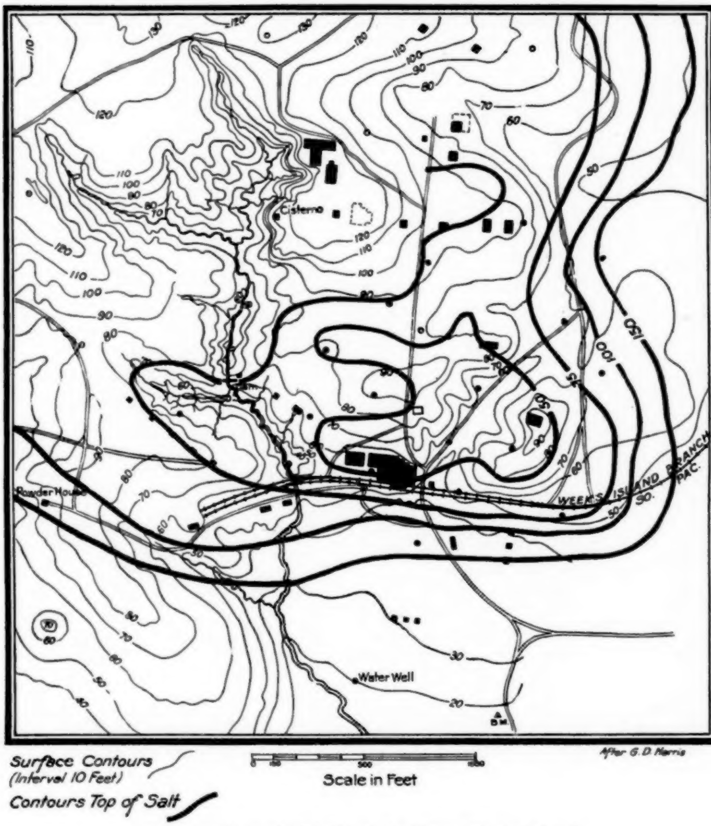


FIG. 8.—Map of Vicinity of the Mine, Weeks Island

inches to 30 or 40 feet thick, followed by sand and gravel down to the salt. In a few of the wells beds of lignite from 3 to 5 feet in thickness were found just above the salt. Blue clay was also met with in some of the wells. The shaft passes through sand for the most part, with an occasional streak of gravel, and a 6-inch stratum of clay just

above the salt. As at Jefferson Island and Avery Island, no important cap rock has been found in any of the numerous test holes.

SALT PRODUCTION

The mine on Weeks Island was opened and is still operated by the Myles Salt Company, of New Orleans. After lowering a cast-iron joint casing 10 feet into the salt mass, the shaft was continued downward for 35 feet, the cylindrical form being maintained. The shaft is lined with wood lagging. Surrounding this there is a wall of concrete 1 foot thick. Then at fairly even intervals there are four rings of asphalt from 3 to 5 feet in height and with bases 2 to 3 feet thick. Moreover, the surface of the salt was heated by hand torches and painted with asphalt. Below the tubular portion, the shaft is square and continues to a total depth of 645 feet.

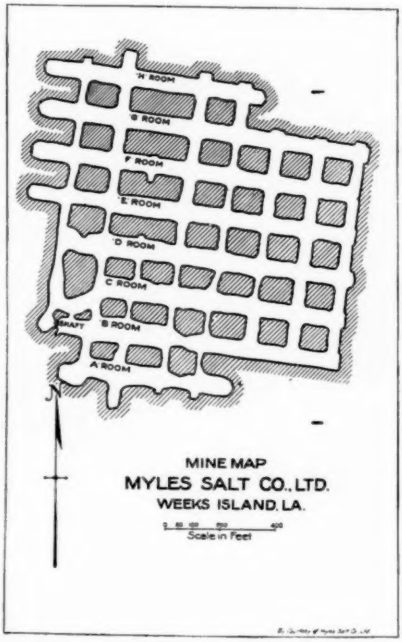


FIG. 9.—Mine Map, Myles Salt Co., Ltd. Weeks Island, La.

Mining operations are conducted in somewhat the same manner as at Jefferson Island and at Avery Island (Fig. 9). The salt is blasted down, loaded by compressed-air shovels into cars, and hauled to the shaft by electric locomotives. At the shaft the salt is passed through a crusher and falls into a bunker, from which it is drawn into a 5-ton skip. Although the system is not balanced and but one skip serves the mine, the hoisting capacity is about 750 tons per ten-hour day.

Because of the incoherent nature of a large part of the salt, a

greater percentage is crushed here than at the other mines. The mill is provided with automatic machinery for filling boxes with table salt, making, filling, and sewing bags with salt, etc. The salt is crushed and sorted to various degrees of fineness, including the finest powder, table salt, coarser grades for packing, and large chunks for cattle.

The total production of the mine from the time when it was opened in 1902 until the present is 2,047,308 tons. The past few years have been the most successful, the production for 1923 having been about 170,588 tons and that for 1924 about 200,000 tons.

EXPLORATION FOR OIL

About twenty years ago three wells were drilled a short distance from the island west of Shell Heap. These reached depths around 1,200 feet, but without finding even a trace of oil. More recently a hole was drilled to a depth of 900 feet on the east shore of the island northeast of Sugar House, but no indications of oil were found. In exploring the salt stock, a hole 919 feet deep was drilled on the edge of the island west of the shaft without striking salt. No trace of oil was found in this hole.

CÔTE BLANCHE

LOCATION

Côte Blanche is on Côte Blanche Bay in the western part of St. Mary's Parish. It is about 20 miles by straight line south of New Iberia, although by the automobile road the distance necessary to travel to reach it is considerably greater. In common with most of the islands of the group, it is nearly surrounded by marshes but is connected to the mainland by a raised dirt-way.

HISTORY

As far back as 1862, immediately after the discovery of salt on Avery Island, shallow pits were sunk here in a search for salt, but without success. However, it was still believed that there was a body of salt beneath the island, and from time to time various attempts were made to find it. In 1919 the Cecil Rhodes Company drilled six holes in the northeastern part of the island and then gave up the project.

In the spring of 1921 the Southern Salt Syndicate was organized, principally of business men from New York, Philadelphia, and New Orleans, for the

purpose of finding and mining salt on the island. Drilling began in June, the work being carried on under Mr. C. J. Webre, of New Iberia, who was also a director in the company. Salt was soon found, and by June, 1922, fifty-four holes had been drilled and the contour of a part of the upper surface had been pretty well determined. Since the uppermost part lies two hundred and ninety-eight feet below the surface and two hundred and ninety-seven feet below the water-level, rather serious difficulties would be met with in sinking a shaft. For this reason, and also because of certain difficulties which have arisen over leases with land-owners, no attempt to mine the salt has yet been made.

PHYSIOGRAPHY

Côte Blanche is nearly circular in form and rises to an elevation of about 100 feet above sea-level (Fig. 10). While resembling both Avery Island and Weeks Island, it is much less rugged, smooth slopes being common and steep-walled ravines entirely absent. There is, however, a wave-formed bluff on the south side which is about 50 feet high. East of this bluff a long arm of sea marsh runs into the island. Rising abruptly from this is Oak Hill, the summit of which is the highest point on the island.

GEOLOGY

Surface.—Because of the smooth contour of the island, very little can be learned of its geology from a study of the surface, which is covered for the most part by a brownish-yellow loamy clay. At one point near the northeast end of the island a gully exposes a rather clayey sand with gravel scattered through it. In the sea cliff on the south side of the island there is exposed a section which is given, in descending order, in Table IX.

TABLE IX

SECTION ON SOUTH SIDE OF CÔTE BLANCHE

	Feet
Light-yellow clay containing some lime	11
Green or bluish-green clay	1
Reddish clay with limestone concretions	7
Fine red silt with thin clay partings every 6 inches	11
Practically the same with more clay	15
Grayish-yellow clay	2

Near the west end there is a fault, with downthrow to the northwest, which would seem to be due to slumping resulting from the solution of salt from below.

Subsurface.—The uppermost part of the salt dome, as determined by the numerous holes which have been drilled on the island, is shown in Figure 10, but this probably represents only a small portion of the entire mass. The evidence of slumping, as afforded by the

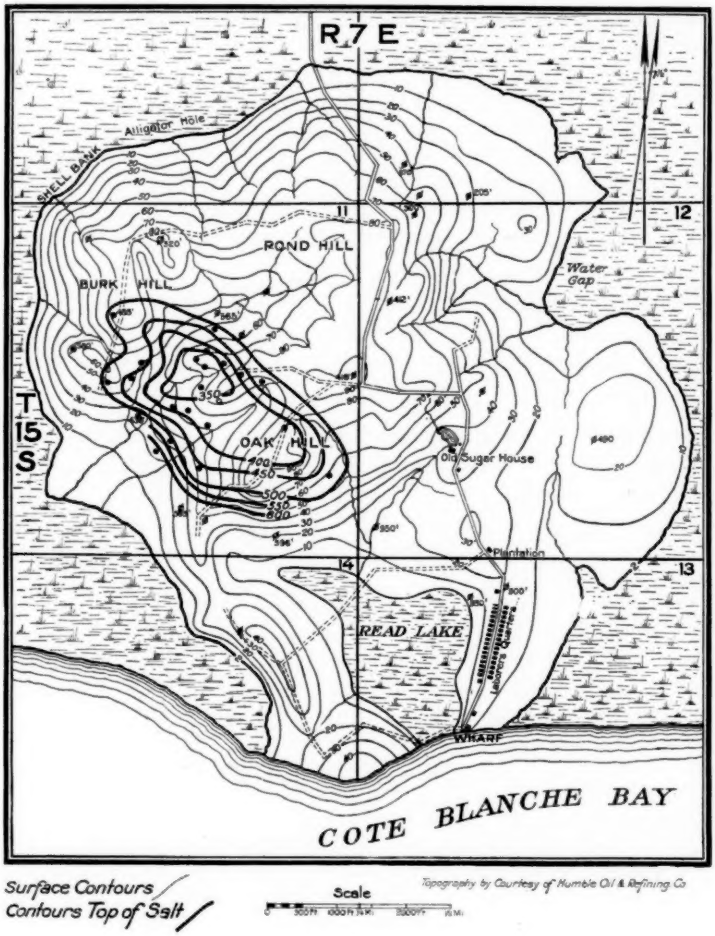


FIG. 10.—Map of Côte Blanche

faults in the sea cliff, certainly suggests that the salt stock extends nearly to the southern boundary of Côte Blanche. Wood Lake may be a sink hole resulting from the same cause.

The general conception that the islands were uplifted by intrusive masses of salt and that, therefore, salt underlies the greater part of each of the islands leads us to believe that it also extends beneath the northeastern portion of this island, where several holes failed to reach salt. Very likely deeper drilling would have been more successful.

The sedimentary beds overlying and surrounding the stock, so far as has been determined by drilling, are of the same general character as those associated with the stocks at Jefferson Island, Avery Island, and Weeks Island. They are almost entirely lenticular sands and clays which vary so greatly in thickness within short distances that exact correlation is practically impossible, and any dome structure which they might possess is completely masked. Only small lentils of cap rock from a few inches up to 4 feet in thickness have been found.

The holes drilled to outline the salt show conclusively that no oil occurs above it, but no hole has tested the possibilities of finding oil around the periphery. However, all of the island is under lease, some of it being in the hands of strong companies, and no doubt will some day be tested.

DEVELOPMENT

The development of the mineral resources of the island has not been carried beyond the prospecting stage.

BELLE ISLE

LOCATION

Belle Isle lies about 8 miles from the mouth of Atchafalaya River near its intersection with Myrtle Bayou, a distributary. It is isolated, being surrounded by a network of bayous and a great sea marsh, but can be reached by boat from Morgan City, a town on the Southern Pacific Railroad about 15 miles to the northeast.

HISTORY

The discovery of rock salt in drilling for artesian water on Jefferson Island in 1895 and the increasing difficulty of mining salt on Avery Island, due to water

in the mine, led to explorations for salt on the other islands of the group. In November, 1896, Captain A. F. Lucas began operations on Belle Isle. In December salt was found in the first test hole at a depth of 373 feet. In 1897 and 1898 the Gulf Company bored thirteen additional holes, and in August, 1898, started a shaft on the site of hole No. 11, where a sill of salt was found at a depth of 103 feet and a solid mass at 140 feet. The shaft was sunk to a depth of 390 feet. A heading was then driven eastward a distance of 340 feet, when water rushed in and rose in the shaft to sea-level within two hours.[50]

A second shaft was started at a distance of ¼ mile southwest of the first, but trouble with quicksand and soft clay was encountered from the beginning. In spite of strenuous work and attempts to freeze the soft materials, the work had to be abandoned after a depth of about 200 feet had been reached. Salt was then raised by pumping it as brine. In this manner several thousand tons were obtained, but, owing to the fact that the salt at this locality is impregnated with oil, it was found difficult to crystallize it, and it was also left with rusty stains. The unconsolidated character of the overburden permitted the escape of brine, and caving was threatened. It became evident that this process would reduce the island to sea-level, and it was abandoned.

In 1906 the New Orleans Mining and Milling Company took over the property and drilled two wells near the north end of the island in an effort to find oil. Although the deeper of these reached 2,411 feet and is less than 1,000 feet north of the old mine shaft, it failed to find salt, indicating that the northern face of the stock is very abrupt. This well reported good showings of gas and oil between 1,396 and 2,989 feet, but no commercial accumulations were found.

During 1907 and 1908, I. N. Knapp drilled three wells on the island, the northernmost of which, No. 1, close to the first shaft, entered salt at about 140 feet and continued in it to 3,171 feet.[53]

During 1916 and 1917, under the stimulus of the demand for sulphur for war purposes, a syndicate of New York capitalists was organized to explore the island. Under the direction of Captain A. F. Lucas, six wells were drilled. In the course of this work the salt mass was found to be of greater extent than was previously thought. A narrow belt of impure sulphur-bearing rock was found extending across the northern part of the island, but it was not considered of sufficient importance to warrant exploitation, and work was discontinued.[54]

In June, 1921, the island was taken over by the Union Sulphur Company. Seven test holes have been drilled and an eighth is now under way.

PHYSIOGRAPHY

Belle Isle is a rudely triangular area with a single range of hills along its northwest side (Fig. 11). This range culminates in four peaks, the highest of which, Lookout Hill, on the westernmost point of the island, is 80 feet high and is a landmark visible for miles from the surrounding marshes. The other high points of the range are

Green Tree Hill, Bald Hill, and Shaft Hill. The rest of the island is a gently sloping, slightly elevated area which extends southeastward from the hills. Willow Pond is a shallow, wooded, fresh-water pond almost in the center of the island.

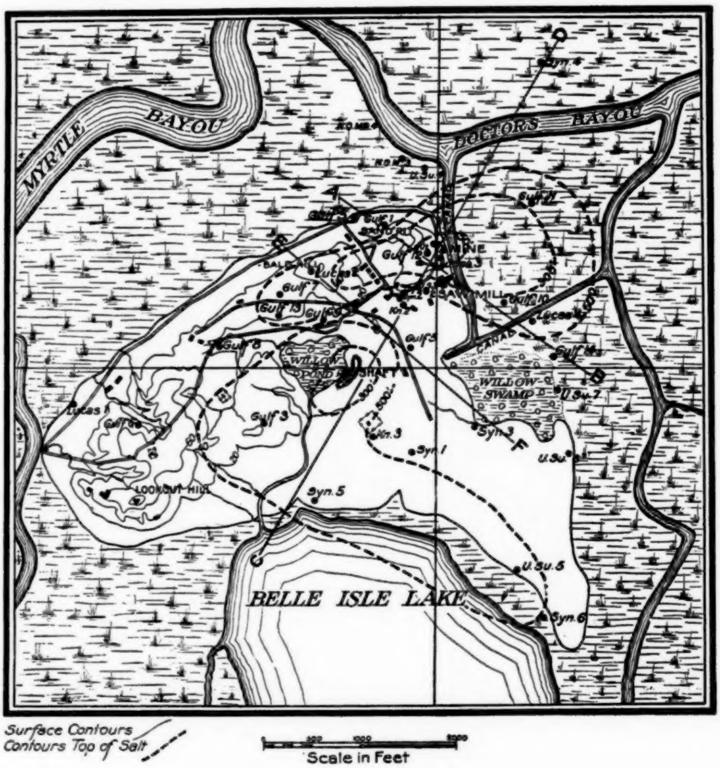


FIG. 11.—Map of Belle Isle

GEOLOGY

Surface.—With the exception of a small area on the eastern side of Shaft Hill, the island is covered with unconsolidated Recent sediments, the surficial layer generally being a grayish-yellow to yellowish-brown clay. This is commonly underlain by a thick mass of sand,

but the beds are lenticular and in some localities the sand is interbedded with lenses of clay, gravel, and shale. The surface clay is particularly well developed on the western part of the island. South of Willow Pond there are several springs, and although this patch of gravel is well elevated above the sea marsh, it is covered with salt grasses. Formerly a spring south of shaft No. 1 yielded small quantities of oil.

On the eastern slope of Shaft Hill there are small outcrops of a gray, iron-stained, rather soft, broken limestone which contains small amounts of galena and chalcopyrite. It is best exposed in a number of pits dug in looking for stone suitable for jetty work. About 150 yards northwest of the limestone outcrop there is a sand pit in which is exposed the section shown in Table X.[50]

TABLE X

SECTION NEAR SHAFT HILL, BELLE ISLE

	Thickness (Feet)
Dark humus-stained clay	0.5
Mottled gray to yellowish-brown clay	2
Mottled gray and brown clay grading downward into finely laminated gray clay	4–7
Massive dark-gray clay	1
Black clay with some pyrite	1–3
Dark conglomerate containing invertebrate remains	0.7
Irregularly bedded brown to white sand with clay pockets and traces of sulphur	2–5

These beds strike approximately N.75° E. and dip 23° NW. The fossils in the dark conglomerate bed are all species represented on the Gulf Coast today. It is therefore clear that the latest movement in the salt mass has been very recent.

Subsurface.—Such information as is available shows that the subsurface geology of Belle Isle is of greater complexity than that of the other members of the group, and although considerable exploration has been done by drilling and shaft-sinking, our present knowledge is insufficient to permit of satisfactory description.

Salt.—The form of the upper portion of the salt stock is very irregular. The results of the first wells by Lucas and the Gulf Company suggests that the topographic ridge along the northwest side

of the island reflects the salt core as to both size and form. While this is true in some degree, the more recent Syndicate and Union Sulphur Company wells show that the salt core is much larger than was formerly believed, for it certainly extends southward to Belle Isle Lake and very likely beneath it for some distance (Fig. 11).

The salt occurs in several forms: large transparent crystals 1 to 8 or more inches long, either in the salt stock proper or scattered through dark-colored clay associated with the upper part of the salt mass; smaller crystals in masses having the appearance of coarse crushed ice or inclosing pieces of dark clay, which gives the salt a dirty earthlike appearance. Gypsum crystals are occasionally found with the large salt crystals.

TABLE XI

Analyses of Light and Dark Salt from Belle Isle

	Dark Salt	Light Salt
Sodium chloride	92.750	96.405
Calcium sulphate (soluble)	....	3.051
Magnesium chloride	....	.074
Magnesium carbonate	2.01	....
Sodium carbonate	.067	....
Sodium sulphate	.836	....
Calcium carbonate	1.804	....
Calcium chloride	....	.226
Ferric and aluminic oxides (Fe_2O_3 and Al_2O_3)	.500	.025
Insoluble matter	3.325	.059

Unlike that at the other islands, the salt at Belle Isle is very impure when first struck, but its purity seems to increase with the depth. The dark, impure salt somewhat resembles the dark streaks of salt at Avery and Weeks Islands, and upon analysis is also found to contain anhydrite. In addition, it contains some gypsum and traces of oil. The difference in chemical composition between the light and dark salt at Belle Isle is shown by the analyses given in Table XI.[50]

The salt mass is overlain and surrounded by sands and clays similar to those found on the other islands. Associated with them, and with the salt, are other materials which have been not found around the other domes of the group. Of these sulphur, barite, galena, sphalerite, pyrite, chalcopyrite, and oil are the most noteworthy.

With the exception of sulphur, these were all found in sinking the first shaft. The section passed through is as shown in Table XII.[50]

The white limestone in the salt near the bottom of the shaft is different from any other yet reported in the Gulf Coast district. It resembles chalk and is composed of extremely small, rounded grains, like those in an oölite except that they are much smaller.

Oil and sulphur.—A number of test holes drilled on the island have encountered oil showings, sulphur rock, and the top of the salt stock. A summary of the results as regards these materials is given in Table XIII.[54]

TABLE XII

SECTION OF MINE SHAFT ON BELLE ISLE

	Depth (Feet)	Thickness (Feet)
Clay	0–4	4
Hard sand	4–13	9
Blue clay	13–30	17
Blue clay and sand	30–40	10
Hard clay and gravel	40–63	23
Blue clay with crystalline masses, 1 to 7 inches in diameter, of barite, galena, sphalerite, pyrite, and chalcopyrite	63–68	5
Blue clay and shells	68–95	27
Impure Black limestone and barite	95–96.5	1.5
Blue clay with masses of barite near the base	96.5–103	6.5
Dark clay with large crystals of salt	103–16	13
Dark Clay with oil	116–17	1
Salt with dark clay	117–42	25
Discolored salt	142–62	20
White limestone	162–62.7	0.7
Dirty salt, purity increasing with depth	162.7–75	12.3

It is of interest to note that Knapp No. 2 reports 590 feet of gypsum, anhydrite, and sulphur immediately above the salt, and that Lucas No. 2 passed through 60 feet of sulphur rock at the same horizon. These two wells must have encountered the sulphur deposit at its maximum thickness, for Syndicate Nos. 3 and 4 found only 5 feet of sulphur rock, and Nos. 1, 5, and 6 found practically none. Although Knapp No. 1 and Gulf I report sulphur, the results of later drilling show that in neither case could there have been any great amount. It is therefore clear that the sulphur deposit is of very limited extent (Fig. 12).

Knapp No. 1 is of particular interest because of the oil showings

found at several horizons. This well entered the salt at a depth of 140 feet and continued in it to 3,171 feet. In the last 600 feet several occurrences of limestone, sand, anhydrite, sulphur, and oil were noted. A canary-yellow oil of 37° Baumé was found a short distance above the salt, at a depth of 125 feet. The well also encountered gas

TABLE XIII

SUMMARY OF EXPLORATIONS ON BELLE ISLE

Name	Well No.	Elevation+ (Feet)	Oil Showings at (Feet)	Sulphur Rock at (Feet)	Top of Salt (Feet)	Total Depth (Feet)
Lucas	1	5	....	....	.....	590
Lucas	2	13	Traces	276	335	410
Lucas	3	7	110–25	*110–25	135	170
Lucas	4	5	135–275	*135–275	325	.....
Gulf Shaft	1	7	116–17	none	117	326
Gulf Shaft	2	5	none?	16.0–190	210	196
Gulf Shaft	H	5	none	340–91	.....	420
Gulf Shaft	I	20	303, 940, 985, 1,086, 1,105, 1,212, 1,365, 1,370	256–85, 870, 1,206	1,545	2,450
Gulf Shaft	J	....	none	none	.....	600
New Orleans Mining Co.	2	....	....	....	.....	1,740
New Orleans Mining Co.	3	....	1,396, 1,506, 1,584, 2,190, 2,270, 2,389	none	.....	2,411
Knapp	1	....	143, 160, 1,850–1,965, 2,100, 2,190 2,500, 2,722, 2,900	*145–59, 2,606–28	150	3,171
Knapp	2	....	390	290–880	880	890
Knapp	3	....	none	none	550	800
Syndicate	1	....	none	none	.....	481
Syndicate	2	....	246–81	286–341	.....	341
Syndicate	3	....	none	391–96	445	566
Syndicate	4	....	320–499	494–99, *565–751	.....	715
Syndicate	5	....	none	none	490	534
Syndicate	6	....	none	*415–505	505	545

*Trace only.

at several places in the salt, and dark-red oil of 37° Baumé in the salt from a depth of 1,500 feet to the bottom of the hole. For the last 300 feet this well labored very hard on account of heavy gas pressure, and was abandoned at a depth of 3,171 feet. Oil was also found in Gulf I. This oil is of very light-color and so pure that it has been successfully burned in lamps without refining. There is also some gas. Although there seems to be but a small flow when allowed to escape freely, it has developed a pressure of 1,000 pounds per square inch

when shut in. Knapp No. 2 is also interesting, as small quantities of very light oil can be obtained from it even at the present time.

Of the eight holes put down by the Union Sulphur Company, only a few are of any particular interest. In No. 2, drilled a short distance from shaft No. 1, soft limestone was found from 300 feet to 320 feet. Below this there was about 80 feet of soft material containing limestone and gypsum. It is reported that some sulphur was also present. From 400 feet to the bottom, 2,200 feet, the hole was in massive salt which was fairly clear except for numerous black specks resembling pepper. Wells Nos. 3 and 7 are said to have encountered the same mass of limestone and gypsum, with some sulphur, found in No. 1. No. 4 was drilled to a depth of 3,900 feet and was in shales and clays, with some beds of sand, practically all the way. No. 5 also found lime, gypsum, and a little sulphur.

Any prediction as to the future of Belle Isle as a producer of oil or sulphur would be hazardous. However, the high gas pressure and the oil so commonly found within the salt body itself would seem to indicate that there is a pool of oil somewhere in the immediate vicinity.

Structure.—The dip of the beds penetrated by the drill on the northwest side of the island is away from the island, and therefore conforms to the structure generally recognized as typical of salt domes; that is, it appears that the salt has been thrust up through sedimentary beds, upturning them immediately around its periphery. The older beds found on the north side of the ridge immediately above the salt are not found on the south side, evidently because this is toward the interior and represents what was once the higher part of the island, and the beds have been removed by erosion. It is of particular interest to note the recency of the movement, as evidenced by the tilted beds containing Recent shells described on another page.

PALEONTOLOGY

The fossils from the sand-pit section are poorly preserved, but so far as they can be identified, they represent a cold-water fauna quite different from the warm-water fauna of the Pliocene.[50] Veatch has

called attention to their resemblance to some phases of the Chesapeake Miocene, but expresses the belief that they are Pleistocene,

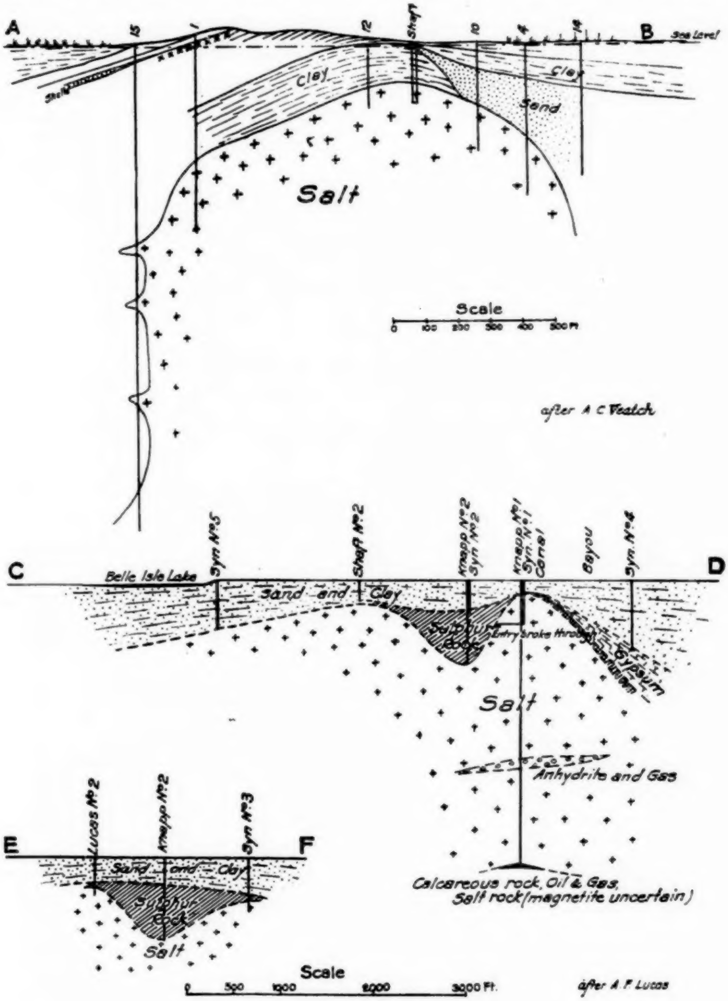


FIG. 12.—Belle Isle—Sections

which view obtains at the present time. The following is a list of the species:

Ostrea virginica
Lithopaga, cf. *caudigera*
Scapharca transversa
Gnathodon cuneatus
Dosinia sp.
Cardium muricatum
Corbula sp.
Mactra sp.
Venus cancellata
Semele truncata
Fulgar canaliculatum

REMARKS

One of the most important problems presented by the Five Islands is the nature of the sediments surrounding the salt stocks, particularly with reference to the depths at which the various Tertiary formations lie and the possibilities of finding oil. At Avery Island a log was found at a depth of 2,643 feet in such a state of preservation that it could hardly be older than Quaternary. There is no conclusive evidence here, nor at the other islands of the group, of the depth to the youngest Tertiary rocks, although the occurrence of oil at Belle Isle suggests that they are probably within reach of the drill.

The depths to which the salt masses extend have not been definitely determined, but if the salt is of Permian age it seems to indicate at least 10,000 or 12,000 feet. At the Humble dome in Texas, the salt core was penetrated by the drill, proving more than 4,000 feet of solid salt with no indication that the bottom was being approached. It therefore seems almost certain that the salt cores beneath the Five Islands extend to depths exceeding 5,000 feet, and they may extend to depths of 10,000 or even 15,000 feet.

Besides being interesting in themselves, the Five Islands deserve special attention because of the light they throw on some of the more general problems presented by the Gulf Coast salt domes.

Nowhere else in this region do we find such convincing evidence of the intrusive nature of salt stocks as at Avery and Weeks Islands. The elongated crystals of salt, the nearly vertical bands in the salt,

and the parallelism of these bands in horizontal section to the periphery of the salt indicate that the salt has come to its present position by flow. The mass of tough red sandstone within the salt stock at Avery Island is further evidence of this for two reasons: first, its long-drawn-out, irregular form, with considerable shattering, is most suggestive of flow; second, its lithological character is altogether different from that of the rocks surrounding the stock, and it must therefore have been brought to its present position from elsewhere, presumably from below. This rock also suggests the age of the salt, for it closely resembles certain Permian rocks in the Texas Panhandle, even in such details as fineness of grain, secondary growth around the quartz grains, and coloring matter. Furthermore, such rock in the Texas Panhandle is often associated with great beds of salt. This evidence, of course, cannot be considered as conclusive, but it is certainly suggestive.

The origin of the cap rock above the salt in the Gulf Coast is a matter of some controversy, but there seems to be little doubt that the cap is in part the residue left by the solution of the upper portion of the salt plug. At Jefferson Island, Avery Island, and Weeks Island, where the salt is rather pure, there is practically nothing that can be called true cap rock. Very little is known about either the purity of the salt or the nature of the cap at Côte Blanche. At Belle Isle the salt is impure and there is considerable cap rock present, and the cap-rock material is essentially the same as the impurities in the salt. Besides impurities scattered through the salt, there are within the salt mass itself beds of limestone, gypsum, and anhydrite. The solution of a mass of salt, leaving behind such beds, and a concentration of the scattered impurities would certainly result in a heavy cap rock. While much of the cap-rock material would retain its original character as a bedded deposit, it would all, in reality, be the residue from the dissolved salt. Even such heavy cap-rock masses as that at Spindletop could easily result in this manner.

The Five Islands present considerable evidence of recent uplift. The elevated position of Recent fossils at Jefferson Island shows that the island was probably uplifted in very late Pleistocene or post-Pleistocene time. At Belle Isle recent uplift is evidenced by beds containing Recent fossils dipping at an angle of 23°. None of the is-

lands shows any evidence of elevated beaches, although they are at tide-level on a coast of recent emergence. Consequently they must have attained their present elevations since the most recent general uplift of the Gulf Coast.

Perhaps every geologist who has worked in the Gulf Coast district has made some attempt at determining tectonic lines along which the salt stocks have risen. With perhaps but one exception, every line proposed has been disputed by evidence quite as convincing as that by which it was supported. The one exception is the line of the Five Islands. The islands lie in practically a straight line. Also, they are very much alike; in fact, every member of the group resembles every other member more closely than it resembles any other dome in the entire Gulf Coast district. This statement covers a great deal, including the fact that they have all been recently uplifted. It would therefore seem that the Five Islands do mark the position of a tectonic line.

COMPARISON OF FIVE ISLANDS WITH THE GREAT SALT DEPOSITS OF THE WORLD

In thickness and purity the salt masses beneath Jefferson Island, Avery Island, and Weeks Island easily outrank any others known in this country. In Europe the famous Strassfurt deposits, of Permian age, show only 685 feet of pure rock salt. The salt wells in strata of the same age at Sperenberg, near Berlin, pass through about 3,800 feet of rock salt. The famous Wieliczka deposits of Galicia, Austria, have an aggregate thickness of 4,600 feet. But this does not represent the thickness of a single mass of salt such as underlies each of the Five Islands. The saliferous formations of Wieliczka consist of lenses of salt separated by beds of clay, marl, and anhydrite. The great deposits of the Salt Range in India are associated with beds of clay, their aggregate thickness generally running from 300 to 700 feet and never exceeding 1,200 feet.

While these various deposits are of considerably greater areal extent than those of the Five Islands which are being mined, there seems little doubt but that the latter rank first of the world's deposits for thickness and purity; they may even rank first as to total tonnage of workable salt.

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THE OIL FIELDS OF NEW YORK STATE

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ABSTRACT

The oil fields of New York comprise some 50,000 acres. The most westerly pool of importance is in Cattaraugus County, and it is the northerly continuation of the Bradford pool of Pennsylvania. To the east in Allegany County is the Richburg pool, the largest and most productive in the state. Several smaller pools occur, among which is the Marsh Pool in Steuben County, the most easterly producing pool in the United States. The oil region of New York is a dissected plateau, as a result of which the main producing sand of Devonian age is found at depths varying from about 900 feet in the valleys to over 2,000 feet for the uplands. In spite of more than 15,000 wells that have been drilled into the oil sands, their structure is but imperfectly known. A general southwest dip is generally recognized, and a few local anticlines and synclines have been determined, but undoubtedly many more are present. Another type of structure is the flat-top, basin-shaped sand lense. The absence of salt water from most parts of the fields and the presence of oil in synclines are noteworthy features. With no important areal expansion of the pools in twenty-five years the present production is greater than fifteen years ago. Increase in production is due largely to "flooding" or restored pressure from water wells.

The little village of Cuba, Allegany County, New York, has the distinction of being the first place in America where oil or petroleum was discovered. This discovery was in 1627—almost three hundred years ago—when a French missionary, Joseph de-la-Roche D'Allion, was led to an oil spring at this place by a Seneca Indian. The oil was highly prized by the Indians for medicinal purposes, and for many years petroleum was known by the name "Seneca oil."

Brief references to Seneca oil are found in many of the early historical documents. For example, Sir William Johnson records in his journal the bringing of some Seneca oil to Niagara Falls in the year 1767.

For many years the oil found floating on the spring at Cuba was the only source of supply in New York State—a quantity sufficient for medical demands—the only use for oil at that time. The regard of the Indians for the value of this spring is shown by the fact that to this day a tract of land 1 mile square in which the spring is located is still owned by the Seneca nation.

In 1864, five years after the first Pennsylvania well was completed, New York's first well was drilled at Limestone, Cattaraugus County, and by 1878, 250 wells were producing. In the early eighties oil was found in Allegany County, and for a number of years the annual state production was over 5,000,000 barrels. In addition to the oil pools of Cattaraugus and Allegany counties, oil is also found in the western portion of Steuben County, and here is located the little Marsh pool, which is the most easterly producing oil pool in the United States.

Within the last twenty-five years no new producing pools of any importance have been discovered in the state, and as the bordering territory has been rather well tested it is not likely that the present area will ever be much extended, although it is possible that other deeper producing sands may be found.

Altogether the oil fields of New York comprise some 50,000 acres, among which are scattered over 14,000 producing wells, their product being of the highest grade of paraffin base oil, and usually commanding the highest price of any oil in the United States. The following figures show comparative prices (1918) taken from one of the volumes of *Mineral Resources:*

TABLE I

CRUDE-OIL PRICES IN DOLLARS PER BARREL

New York	\$4.08	Indiana	\$2.31
Pennsylvania	3.99	Mid-Continent	2.19
West Virginia	4.02	Gulf	1.69
Kentucky-Tennessee	2.58	Rocky Mountains	1.44
Lima, Ohio	2.31	California	1.21

In color the New York oil varies from light yellow on the borders of the fields to almost black, but dark green is by far the most prevailing color. In specific gravity at 10° C., the oil varies from 38° to 47° Baumé, most operators reporting 42° Baumé. It is a singular fact that of the many oil fields discovered in the United States since the first New York and Pennsylvania fields were opened up, none have produced oil more valuable in gasoline and by-products content than these first developed fields.

The oil region of New York is a dissected plateau with considerable relief, as a result of which the main producing sand of Devonian

age is found at depths varying from about 900 feet in the valleys to over 2,000 feet on the uplands. One remarkable feature of the wells is their long life. A few wells have produced for a period of over forty years. Wells are common that have produced for a period of thirty years, and perhaps more than half of the 14,000 have been producing for over twenty years. The long life of most of the New York wells is due to the hard, compact nature of the sandstones, which are much like building stones, and which have a low porosity and a low but ever present gas pressure. The main pools, however, are without water—the terror of many, if not of most, oil fields.

In spite of the large number of wells that have been drilled, the structures of the oil sands are but imperfectly known. A general southwest dip is often recognized, and a few local anticlines and synclines have been determined, but undoubtedly many more are present and recent studies indicate the presence of a few closed folds. Another type of structure is the flat, basin-shaped sand lens. The absence of water from most parts of the field and the presence of oil in synclines are noteworthy features. The lack of reliable well logs has hindered greatly in determining structures, and only in the last few years has the importance of reliable well logs been recognized by many of the operators. It is not stretching the truth to say that some operators know more about the structure of some of the western fields than they do about their own leases. Geologists were not employed until the fields were thought to be nearly exhausted and much data which might have been of value were no longer available.

Altogether the New York oil fields with all their years of productiveness have yielded but 70,000,000 barrels of oil. From an annual production of over 5,000,000 barrels in the early eighties, there was an annual decline until a dozen years ago the annual production had declined to about three-fourths of a million barrels. It then seemed that the life of the fields was close at hand, overwhelmed, as it were, by the great new fields of the west and southwest. Extensive border and extraneous drilling were and had been without results of importance. No new pools were discovered. New wells were drilled between the wells already producing but these did not stem the annual decline.

It had been known for many years that as a result of accidental and in some cases the purposeful flooding of some wells there was an increased production of nearby wells. It was or soon became known too by most of the operators that by the usual method of production but 10 to 15 per cent of the oil contained in the sand was being recovered. It was believed that if water could be used to take the place of the fast-declining gas pressure, production could be continued for a number of years.

Largely as a result of "flooding" which is now being regularly employed in many parts of New York fields, production has been increased from three-fourths of a million to one and one-fourth million barrels annually. And this result has been accomplished in a field which has had no important lateral expansion in twenty-five years and a field which has been producing for more than forty years.

The method of "flooding" is briefly as follows: Water is introduced into an oil well. The pressure created by a column of water, say 1,000 feet high, results in driving the oil away from the bottom of the well in advance of the flood of water. Surrounding this well filled with water, other wells are drilled and into them oil is forced by the pressure of the water from the water well. The wells drilled into the flood of oil are pumped until the water reaches them. They are then made into water wells and an ever enlarging circular flood of oil is driven away from these wells. New wells are again drilled into the flood of oil away from the new water wells and the process is then repeated. The method just described is known as the circular flood. Within the last two years there has been developed what is known as the "line flood." This differs from the method described only in method of arrangement of wells, and but little attention is paid to wells previously drilled in the district. Instead of using an old oil well for the first water well, an entirely new row of water swell is drilled. Water wells, sometimes as many as twenty-five in number, are drilled in a row 150 feet apart. These wells all extend to the oil sand but are not pumped. They are simply filled with water and left for a year or more. Then two wells are drilled for each water well at right angles from the point midway between the water wells and 150 feet distant from the water wells. As in the circular floods,

when the oil wells go to water they in turn are made water wells, and new rows of wells for oil are drilled.

Gratifying results as a result of "flooding" are reported. Some leases show an additional recovery of from 2,000 to over 5,000 barrels per acre. The higher figures are from leases that have an exceptional thickness of sand and the wells deep enough to give high-water pressure. What is believed to be a conservative estimate of future production for the fields places the amount at 90,000,000 barrels as against 70,000,000 barrels of past production.

Due to this method of producing oil, the life of the New York petroleum industry will be prolonged many years into the future. The floods travel very slowly, from 50 to 200 feet per year, and so quite likely oil will be produced in this state for a period of thirty to fifty or more years, the time depending largely on the number of floods started.

GEOLOGICAL NOTES

THE APPLICATION OF THE ALIGNMENT CHART TO PETROLEUM ENGINEERING

INTRODUCTION

The alignment chart, in its simplest form, is comprised of a series of three lines, each representing a quantity, so scaled and arranged that a straight line intersecting all of these lines intersects them at values for each respective quantity which will satisfy the equation of the relations of the quantities. In the simplest form, there are but three variables, one the function of the other two. In complicated equations, the alignment charts take on more complex forms. Constants, either as coefficients or exponents to any of the variables, affect only the arrangement of the lines and the values scaled on them, without adding any to the complexity of design, and consequently increases their utility.

This paper will deal with a practical method of designing alignment charts to meet the petroleum engineer's particular needs and their uses and limitations in practice.

METHODS OF DESIGN

There are two general methods of designing and constructing alignment charts, namely, (1) the design from a pure mathematical analysis as projected by Peddle[1] and (2) the design from a graphic analysis. A good analogy of the two methods is found in the two following methods of field mapping: (1) the mathematical way is to procure the data in the field with a transit and stadia or chain, enter the data in a transit book, compute the data, and from the computations plat the map; and (2) the well-known plane-table method of mapping in the field by graphical methods.

The mathematical method requires high technique and skill in platting the chart along the mathematical lines computed, especially in the more complex charts. This method of designing and platting alignment charts has been very well discussed by Peddle and will not be discussed further in this paper.

The graphical method of designing alignment charts necessarily involves a mathematical understanding of the problems to be solved, a

[1] John B. Peddle, *The Construction of Graphic Charts*.

partial knowledge of the mathematics of the alignment chart to be designed, and very little, if any, knowledge of the mathematics involved in using the chart.

In the design of an alignment chart it must be held in mind that the accuracy of the chart proper varies directly with the accuracy of platting, the size of the chart, and inversely with the range of its variables. A chart with a high range of the variables will lack minute reading, and vice versa. From this point, the laying out of an alignment chart will be carried through with a concrete example.

The petroleum engineer and geologist is frequently called upon to estimate the quantity of petroleum in a sand, or other porous formation, by the porosity-and-saturation method. His first step is to make an estimate of the voids per acre. To accomplish this, there may be designed by the graphical method an alignment chart for determining the volume in United States barrels of 42 gallons of the total voids per acre, this chart to be used in all fields. The range of thickness of the stratum, or strata, that might come up for consideration, the range of porosity, and the resultant range of voids per acre must all be determined.

In this case we will decide that practically all petroleum-bearing formations range from 10 to 2,000 feet in thickness. We then find the logarithmic scale that comes the closest to this range, and that can be plotted on the sheet. A variable supply of logarithmic scales can be obtained from logarithmic cross-section paper, but care should be exercised in checking their accuracy. The variable thickness in feet is then plotted on a straight line in logarithmic scale on the left side of the sheet, shown as line *A* in Figure 1. The larger values are above, and smaller values are below.

On the right side of the sheet, and on the line *C*, which is parallel to the other, are plotted the values for voids in barrels. The range of these values must be chosen. An acre-foot equals 43,560 cubic feet or 7,758.357 barrels. A stratum 10 feet thick and having a porosity of 1 per cent will by computation have 775.8 barrels of voids. Therefore we can take 700 as our minimum on this scale. In the same way we could compute the larger limits, but we will adopt 2,500,000, which has been found highly satisfactory. A logarithmic scale is then chosen, on which this range of 700 to 2,500,000 can be suitably platted on line *C* on the right-hand side of the sheet. In contrast to the other line, *A*, the smaller values are platted on line *C* above, and the larger below. Attention should be called at this time to the fact that there is no relation between the sizes of these two logarithmic scales, nor any definite spacing between them.

The platting of the percentage porosity on line *B* is next. We may choose a range of 1 to 35 per cent. In a simple chart of this nature, the line *B* will be found to be a straight line parallel to the other two. It was

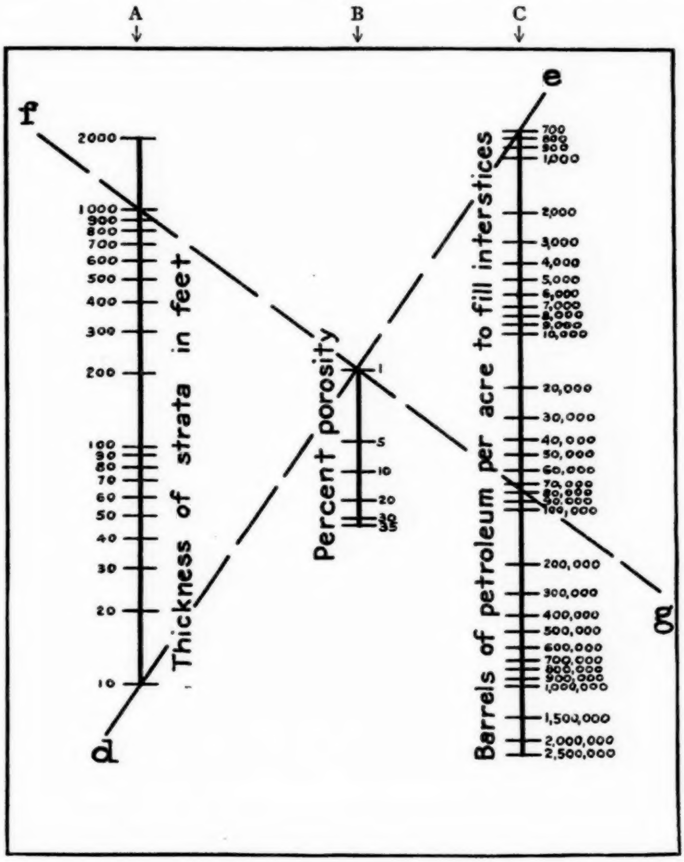

FIG. 1

found that a stratum 1 foot thick and of 1 per cent porosity contained 775.58 barrels of voids. We then draw a straight line (*de*) through the value 10 on line *A* and value 775.58 on line *C*. Similarly, a stratum 1,000

feet thick and of 1 per cent porosity contains 77,558.4 barrels of voids. The line (*fg*) through these two values on their respective lines is drawn. At the point where lines (*de*) and (*fg*) intersect is the point on line *B* which has the value of 1 per cent. It also establishes the position of line *B* to lines *A* and *C*. The next step is to find the point for 10 per cent porosity, which is accomplished in the same manner, and checks the accuracy of locating line *B*. If the porosity is to range from 1 to 35 per cent as in this chart, it will require the computation of the barrels of voids for each per cent to be platted. In this particular case it will be best to use a thickness of 100 feet so that the straight edge will be as nearly at right angles to the line *B* as possible. Another set of computations should be taken from another thickness. Two hundred feet in this case would be practical, to serve as a check in platting the values on line *B*. The constants, that is the relation of acre-feet to barrels in this particular problem, have been allowed for in the graphical method of platting.

This concrete case has been given to show the general method of attack, and was used by the authors in designing the charts in their *Petroleum Engineering*.[1] No attempt will be made with other problems as there is a great variety of alignment charts, and the ingenuity of the designer must be called upon to plat the chart that will best meet the requirements before him.

UTILITY OF THE ALIGNMENT CHART

The utility of the alignment chart is similar to that of the slide rule. In general, they have their greatest value where the known variables are estimates. They have a distinct advantage over the slide rule in that the engineer is not required to remember a formula. How many times has the engineer been asked a question that required a simple computation involving a forgotten formula? The alignment chart illustrated here is one that is very practical. Here we have the percentage porosity which is an estimate, and frequently hard to determine. An alignment chart, in this case, is as accurate as the most minute computations, because at least one of the two variables is a pure estimate, usually with some basis. Other practical alignment charts for the petroleum engineer are: barometric temperature corrections; relations between the dip, thickness, depth, etc., of strata; estimates of the rate of pumping of various sizes of pumps and the rapidity of stroke; capacity within and between casing in terms of barrels and sacks of cement; rapid computations of tanks, square pits, and partially filled horizontal tanks; correction of degrees

[1] Phelps and Lake.

Baumé for temperature and water content; and any number of others could be designed. In some of the aforementioned problems, accurate tables have been computed and are available to the engineer, but most frequently interpolations between standard sizes must be made, while the alignment chart gives all values within their range.

The alignment chart has the disadvantage that it is usually designed for one problem. It also requires a straight edge, that is, straight to obtain a maximum degree of accuracy. Probably the best straight edge for the use of the alignment charts can be constructed out of a strip of transparent celluloid, by scratching a straight line on it, and with an ordinary fountain pen fill the scratch with writing fluid, allow to dry, then test for accuracy.

CONCLUSIONS

There are numerous problems in the petroleum industry that can be materially shortened, with a partial sacrifice of false accuracy, by the use of well-designed alignment charts. There are problems to which they are not practical, but there are many to which they are very well adapted. They are another short cut for many petroleum engineering problems. They save wear and tear of mental energy, and time, which means money saved.

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THE EÖTVÖS TORSION BALANCE

Probably the best treatise on the Eötvös torsion balance, an instrument which is coming into use in this country, is a recently published paper by Dr. Desiderius Pekár.[1] Doctor Pekár has been in charge of field work since 1891, having also assisted in laboratory experiments before the torsional balance was sufficiently developed to be used for practical purposes. Now he is at the head of Eötvös Geophysical Institute at Budapest, Hungary.

Baron Roland von Eötvös, professor of physics at the University of Budapest, died April 8, 1919. The scientific importance of new methods employed in his invention has been recognized by the school of philosophy, University of Göttingen, Germany, which granted him the first Benecke prize in 1909. In geophysical investigations (especially of isostasy) Eötvös' balance renders helpful services. It is also of great assistance in

[1] *Die Drehwage des Barons Roland v. Eötvös.* Budapest, 1923.

geodetic research carried on by the International Committee for Earth Measurements; which proved that the earth ball has a complicated form and not that of a simple, flattened sphere. The application for geologic work was first suggested by the Hungarian geologist, Dr. Hugo Böckh, in the determining of subsurface structure, and will be discussed later. In seismologic investigations the balance is used for the registering of dislocation of great masses and the shifting of unsettled strata caused by volcanic forces, which are most dangerous along tectonic lines of weakness.

The Eötvös balance is being used in most of the European countries and Japan for different purposes. First to employ it in connection with search for oil and gas were the Whitehall Petroleum Corporation, London, England, and the Amerada Petroleum Corporation in the United States.

A meager bibliography of the Eötvös method shows eleven Hungarian, German, and French papers published in transactions of scientific societies.

The basic principle of the Eötvös method can be defined as the measuring of regional variations of gravity with the instrument invented by him. Two elements of gravity must be taken under consideration: (1) direction and (2) intensity. The direction shown by a plumb-line is not exactly perpendicular, pointing to the center of earth, but diverges by reason of the centrifugal force of the earth's rotation. An absolutely perpendicular direction can be determined only by astronomic and geodetic measurements. The gravity is expressed in C.G.S. units (metric system), and its intensity is determined by the duration of pendulum oscillations. The gravity is a resultant of gravitation and the centrifugal force caused by the rotation of the earth. After Newton, gravitation P with which two material bodies, m_1 and m_2, attract each other equals the product of m_1 and m_2 divided by the square of the distance r separating them and multiplied by the constant of gravitation f. The value of f, experimentally determined, is 0.0000000663 C.G.S. (dynes).

$$P = 66.3 \times 10^{-9} \text{ C.G.S.} \frac{m_1 m_2}{r^2}$$

This equation shows clearly that gravity decreases with increasing elevation above sea-level. The centrifugal force is proportional to the radius of rotation, therefore is zero at the poles and reaches its maximum (equal approximately 1:300 of gravitation) at the Equator. Variations caused by latitude and altitude are called regular or normal variations. Other ir-

regular variations are caused by (1) the fact that the surface of the earth is not ideally level, and, as is well known, in proximity to mountains the plumb-line swings toward them; and (2) by difference in specific gravity of the subjacent rocks. The greater the specific gravity, the greater the attraction.

Suppose there is a dome of great dimensions, composed of material of 2.6 specific gravity, buried beneath a level stratum of material with 1.8 specific gravity. The gravity on the surface just above the apex of the dome will be the greatest and will gradually decrease in all directions away from it. The direction of the plumb-line will be practically perpendicular above the apex and in proximity to it will be slightly inclined toward the dome, in extreme cases a few seconds, while the change of gravity never exceeds some 1/100,000ths of the gravity.

Measurements conducted with gravimeter (abbr. for "gravity variometer," as the Eötvös field instrument is called) furnish the following full values: $\frac{\delta^2 U}{\delta x \delta z}$, $\frac{\delta^2 U}{\delta y \delta z}$, $\left(\frac{\delta^2 U}{\delta y^2} - \frac{\delta^2 U}{\delta x^2}\right)$, and $\frac{\delta^2 U}{\delta x \delta y}$, in which U=potential function of gravity, x=the axis pointing north, y=axis pointing east and z=axis pointing up from the center of the system of co-ordinates situated in the center of gravity of the balance. Full values are not suitable for further calculation as they are influenced by accidental unevenness of the ground. To eliminate this either the observation station should be moved to a point located on flat ground, or, if this is not desirable, the surroundings within 100 meters from the instrument are carefully spirit leveled and the "influence of terrain," also caused by ditches, dams, etc., is calculated in an appropriate way. Influence of terrain subtracted from full values gives topographic values. Normal values subtracted from topographic values give values of topographic deviations or deviations of gravitation. These are caused by masses on the surface and buried masses. By subtracting "cartographic deviations" caused by influence of surface topography, which can be determined from a map, values of "subterranean deviations" are obtained.

The acceleration of gravity $g = \frac{\delta U}{\delta z}$; $\frac{\delta^2 U}{\delta x \delta z} = \frac{\delta g}{\delta x}$ and $\frac{\delta^2 U}{\delta y \delta z} = \frac{\delta g}{\delta y}$. These equations indicate the change of acceleration or of gravity caused by movement to the east or north, and the resultant gives the direction and intensity of greatest change, called "gradient." Gradients are expressed in 10^{-9} C.G.S. units and indicate the increase of force (in dynes) caused by moving forward 1 centimeter in this direction.

Gradients caused by subterranean influence, plotted on a map, per-

mit conclusions as to subsurface conditions, since they point toward masses of greater specific gravity and their length is drawn in proportion to variation of gravity.

If there is a sufficient number of data obtained by making measurements in many stations, the value of gravity can be determined for any desired point. This must correspond with values furnished by a pendulum, and the correctness of results obtained by the Eötvös method can be checked with the pendulum.

A curve connecting points at which gravity is the same is called an "isogamme." Isogammes caused by subterranean influence, plotted on a map, will naturally coincide with isohypses (curves connecting points of equal altitude) or structural contours.

To eliminate disturbances which could be caused by wind, changes of temperature, and atmospheric electricity, the gravimeter is placed in a water-proof tent with double walls, the space between filled with wood shavings, and measurements are made at night.

The gravimeter consists of a tripod, socket movable on its vertical axis, and the instrument proper. Its "soul" is a platinum-iridium wire of 0.04 millimeter diameter, a specially treated torsion wire, in a vertical position. It is protected from outside influences by a triple brass pipe 3–5 millimeters thick. Attached to this wire is an aluminum beam of considerable moment of inertia, which can move in a horizontal plane. From the shorter end of this beam is suspended a weight of about 30 grams of platinum on a thin wire also protected by brass housing. On the longer end is mounted a telescope which permits direct reading in a mirror, instead of photographic registration (as was practiced during the period of early development) of torsion to which the wire was subjected by horizontal components. The angle of turning, when the balance comes to a standstill after about one hour of swinging, serves as basis for all calculations. As has been previously mentioned, forces to be measured are extremely small and require instruments of great sensitiveness and precision, and these are obtained, to an unbelievable degree, by applying a scientifically prepared wire of high elasticity.

The instrument used in field work at present is a double gravimeter carrying two telescopes and two platinum weights. Its height is about 2 meters and length of the beam 1.15 meters, as manufactured by the Ferdinand Süss Mechanical and Optical Company.

Neither the paper reviewed, nor another article by the same author entitled, "Die bei Feldmessung angewendete Drehwage von Baron

Roland v. Eötvös," published in *Zeitschrift für Instrumentenkunde*, Berlin, 1922, describes actual operation of the instrument, but deals only with the theory of the Eötvös method.

In a personal communication Dr. George Steiner states that the present price of an adjusted double gravimeter delivered in the United States is $5,000 plus import duty. The Eötvös Institute furnishes all formulas, as physical and torsional constants, moment of inertia, etc., and trains the observer for the purchaser. It appears that the only way in which one can obtain working knowledge is by a study of several months at the Eötvös Geophysical Institute in Budapest.

ADAM WRÓBLEWSKI

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OZOCERITE AND NAPHTHA ON LAKE BAIKAL, SIBERIA

To the people dwelling on the shores of Lake Baikal, Siberia, ozocerite has been known from time out of mind, has been collected by them in pieces of different sizes, from the beaches of the eastern shore, and has been used as a lubricant, alone or mixed with blubber of Baikal seal or with tar. The first scientific mention of this occurrence of the mineral was by Georgi in 1775. At that time specimens were brought to Petersburg and deposited in the Mineralogical Museum of the Russian Academy of Sciences.

During a long time nothing more was known about the locality, and sometimes even the record of finding ozocerite on the lake was considered questionable. This doubt may have been provoked partly by the fact that some localities of so-called mountain oil or wax reported on the shores of Baikal, as indeed in other parts of Siberia, were found to be thick solutions of iron-vitriol, flowing out of pyrites and marcasite-bearing rocks, as a syrup-like oily liquid.

On his travels in Siberia the present writer came across a locality of mountain oil which he found to be a limy, opalescent water dropped from the roof of a small cave in limestone. The locality was claimed by somebody, and its legal proprietor was looking, probably, for an investor.

A commercial interest in the Baikal ozocerite (or, to use the scientific name of the mineral, Baikerit), in connection with suggested finding of naphtha, has appeared only since the last years of the past century, when applications were made to Russian officials by different persons requesting permission to investigate the locality.

In 1902 the Mining Department in Irkutsk, Siberia, appointed a

mining engineer, W. D. Ryasanoff, to investigate the district. His report was so favorable that the part of the eastern shore of the lake, including the deltas of the rivers Selenga and Barguzin, was proclaimed, in accordance with Russian laws, "an actually naphtha-bearing land."

There are no documentary data preserved in Siberian archives except a few of Ryasanoff's reports of very general character. Considerable drilling was undertaken in the region of the northern part of the Selenga delta and in the bay of Barguzin River, a few of the wells being 945–80 feet deep, and some of them being located on the ice of the lake.[1] Some traces of oil were found, but, so far as known, no specimens of it were collected. Sand impregnated with ozocerite was reported. In many places the outflowing of gases was discovered below ice.

Ryasanoff was invited in 1905–6 by a private concern to investigate its oil claims in the delta of the river Barguzin. A. Arsentieff, mining engineer, at that time a student of a mining school, was appointed as an assistant. He has published now a very important paper on this matter, giving most of the data for the present article.[2] Six wells, the deepest of them about 1,080 feet, were completed by Ryasanoff, three of them being recorded in Arsentieff's paper. The mud, clay, and sand deposits of the delta were not pierced, and underlying rocks not discovered. Gases, films of oil on the surface of outflowing water, sands smeared with oil, and pieces of ozocerite were reported found in different strata, but no specimen of naphtha could be collected. The succession of strata in the different wells was very irregular, and no common horizons could be established. Remnants of wood, often very little altered, pine cones, and rarely shells were found within different strata. During early spring, when Biakal is still covered with ice, all gas localities along the shore were investigated. Owing to the comparatively high temperature of the emanating gases, ice was melting above the seepages, and ice holes of different sizes (6–15 feet in diameter) resulted. In some of them hydrogen sulphide was discovered, connected, probably, with sulphuric springs on the bottom of the lake; in others, hydrocarbons of undetermined nature. It was colorless, without odor, and burned with colorless flame without soot. It was

[1] During the long and cold Siberian winter, ice, covering Lake Baikal, attains a thickness over 5 feet and can easily support the whole installation set up in drilling.

[2] A. Arsentieff, "On the Question of Oil of Baikal-Lake," *Records of the Geological Committee of the Russian Far East*, No. 30, 1924 (in Russian, with a short summary in French), 29 pp., 1 map, 1 table of drillings. The question is touched in papers of Russian geologists, inaccessible to the present writer, dealing with the geology of the lake or directly with its naphtha and ozocerite localities. In the most important of them, by Kalitsky, there are a few analyses lacking in Arsentieff's paper.

of the same character as gas emanating in marshes, and Arsentieff points out its similarity to methane. Gases of the latter kind were escaping, sometimes very violently, water in the ice holes strongly resembling vigorous boiling. Gas emanations were considered by Ryasanoff as an indisputable indication of the presence of naphtha, since their origin is presumably connected, but even within the "boiling" holes no traces of oil were discovered, not even thin films on the surface of the water. In the distribution of gas seepages no regularity was discovered, nor connection with any tectonic lines, such as suggested formerly by Ryasanoff.

All these phenomena are connected exclusively with delta deposits of the rivers Selenga and Barguzin, and they are not known elsewhere on the lake. Hydrocarbons were found mostly in the submerged parts of deltas, or it may be they were more apparent there. No naphtha accumulation was found, but only a local and feeble smearing of sand with oil. An ozocerite horizon rumored within the delta of Selenga might be nothing but sand containing pieces of ozocerite such as was found in the wells drilled within the delta of Barguzin. The beach on the eastern shore of Baikal would produce such a horizon after every storm, if covered with slime.

The sum of the evidence brings the author to the only possible conclusion. Naphtha on the Baikal is found in delta deposits in a primary location, originated by the decomposition of organic matter, buried within the strata of the delta. Fish and seal die in great numbers near shore in water poisoned with hydrogen sulphide, especially below ice when more gas is dissolved in cold water, its emanation is more difficult, and the water is not aerated. After the ice is gone, great amounts of fish and carcasses of seals are found on the beach, where they could be quickly buried in silt, brought by a spring overflow. Accumulations of organic stuff, produced in this way, might be large enough to explain the origin of small pockets of naphtha and ozocerite.

The results of the investigations recorded are certainly very discouraging. More ozocerite and oil were collected by the local people after every storm on the beach, or found swimming on the surface of the lake and within ice holes, than were taken during the drilling to comparatively deep horizons. So far as present data show, the locality has no commercial value, but is very interesting from a theoretical point of view.

In spite of the fact that the Mining Department in Irkutsk is ready to continue the investigations, very little can be expected of commercial importance. If work is continued, it should be done scientifically, and not in confining drilling to "actually naphtha-bearing land." In one

case only does it seem that Arsentieff's ideas could be wrong and the whole question of Baikal oil would need to be revised; that is if new deep drilling should find below the delta deposits sedimentary strata of Tertiary or Jurassic age, and naphtha should be discovered in them. From a purely geological point of view, this is not impossible, but at present there are no grounds for such an expectation.

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EARLY PENNSYLVANIAN "RED BEDS" IN THE MID-CONTINENT REGION

Two articles have recently appeared, one by Frank Greene[2] calling attention to the possible occurrence of Chester red beds in the Mid-Continent region, and the other by Russell Tarr[3] in refutation to this possibility. In support of the latter view, the writer would like to give additional evidence.

Cuttings from a well in southeastern Sumner County, Kansas, have been examined, and they show the following stratigraphic section: 10 feet of red shale, 15 feet of sand which is correlated with the Bartlesville, and about 25 feet of dark shale which rests unconformably upon the Boone chert.

Despite the suggested Chester correlation as noted by Greene of the red bed and the shale below, the writer has identified a fairly well-preserved specimen of *Chonetes mesolobus* and two ostracods from the shale directly above the chert. The presence of *Chonetes mesolobus* at once rejects the possibility of a Chester age for the red bed. It is also of interest to note that the ostracods found have hitherto been limited to the Boggy and younger formations of Oklahoma.

In conclusion, the writer suggests that this red bed represents, in part, the period between Pottsville and Allegheny deposition.

GEORGE S. BUCHANAN

TULSA, OKLAHOMA
May, 1925

[1] Introduced by R. H. Johnson.

[2] This *Bulletin*, Vol. 7 (1923), No. 6.

[3] *Ibid.*, Vol. 9 (1925), No. 2.

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BERTRAND L. JOHNSON and L. M. JONES

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma.

(Names of sponsors are placed beneath the name of each applicant.)

FOR FULL MEMBERSHIP

Donald G. Barnett, San Antonio, Texas
  George D. Morgan, J. W. Beede, L. C. Snider
Ralph E. Bending, Eureka, Kansas
  Marvin Lee, C. R. Thomas, F. L. Aurin
Gilbert E. Cheda, El Dorado, Arkansas
  Harold E. Boyd, Christion Vrang, E. G. Sinclair
Jerome A. Chevalier, Pawhuska, Oklahoma
  F. S. Prout, C. L. Severy, W. R. Hamilton
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  F. E. Vaughan, John C. Myers, John R. Suman
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  W. T. Thom, Jr., Heath M. Robinson, R. B. Whitehead
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  F. S. Hudson, E. F. Davis, Roy R. Morse
Godfrey F. Kaufmann, Tampico, Mexico
  Paul Weaver, W. S. Adkins, Walt M. Small
L. C. Keeley, Tampico, Mexico
  P. H. Bohart, Paul Weaver, A. H. Noble
Andrew K. McGill, Cartagena, Colombia, South America
  Oliver B. Hopkins, A. F. Dixon, Theodore A. Link
Donald K. Mackay, Dallas, Texas
  F. H. Lahee, Herbert J. Weeks, D. M. Collingwood
D. M. Morgan, Ponca City, Oklahoma
  Clarence M. Sale, R. B. Roark, J. M. Armstrong

Edgar K. Soper, New York City
V. R. Garfias, A. C. Veatch, William B. Heroy
Daniel Trumpy, Aguila, Puerto Mexico, Mexico
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Cornelius G. Willis, Houston, Texas
R. E. Collom, Carl H. Beal, R. M. Barnes

FOR ASSOCIATE MEMBERSHIP

G. Frank Aldrich, Tulsa, Oklahoma
Henry A. Ley, T. E. Weirich, Everett C. Parker
Burton F. Amsden, Denver, Colorado
Charles M. Rath, F. M. Van Tuyl, Max W. Ball
Philip Andrews, Port of Spain, Trinidad, British West Indies
G. C. Gester, F. W. Rohwer, Vergil N. Brown
James L. Ballard, French Lick Springs, Indiana
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
Paul W. Banks, Golden, Colorado
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
Elliott V. H. Bauserman, Charleston, West Virginia
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
R. Irwin Brown, Bakersfield, California
E. J. Young, S. H. Gester, E. Huguenin
George R. Chatburn, Jr., Tulsa, Oklahoma
Claude F. Dally, Kent F. Kimball, E. F. Shea
Robert S. Christie, Crum Lynne, Pennsylvania
Roswell H. Johnson, S. G. Huntley, R. E. Somers
William W. Clawson, Bartlesville, Oklahoma
R. S. Knappen, C. S. Corbett, V. F. Marsters
Edwin G. Cole, Tulsa, Oklahoma
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
Ronald K. DeFord, Denver, Colorado
V. M. Van Tuyl, Charles M. Rath, Harold T. Morley
Frank Donohue, Phillipsburg, Kansas
F. F. Hintze, David Donoghue, Erasmus Haworth
John W. Emch, Fort Worth, Texas
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Jack Gaddess, Oil City, Pennsylvania
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Robert L. Jones, Norman, Oklahoma
S. Weidman, V. E. Monnett, Charles N. Gould

Oscar H. Kilpatrick, Pittsburgh, Pennsylvania
A. M. Hagan, Ray V. Hennen, James V. Howe
Albert H. Koschmann, Stillwater, Oklahoma
Charles N. Gould, W. H. Twenhofel, W. W. Rubey
Alvin P. Loskamp, Shawnee, Oklahoma
James M. Douglas, W. H. Geis, W. L. Walker
Paul McCune, Denver, Colorado
Carroll H. Wegemann, Charles M. Rath, Harold T. Morley
C. R. McKnight, Shreveport, Louisiana
W. C. Spooner, S. P. Borden, A. F. Crider
Vernon L. Mattson, South Charleston, West Virginia
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
Thomas F. Newman, Denver, Colorado
Carroll H. Wegemann, Charles M. Rath, D. E. Lounsbery
Robert E. Reynolds, Wichita, Kansas
F. K. Foster, A. F. Morris, Dollie Radler
Henry Rogatz, New York, New York
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
James H. Sargent, Bakersfield, California
E. J. Young, S. H. Gester, E. Huguenin
Stanley R. Say, Tampico, Mexico
Walt M. Small, A. H. Noble, John M. Muir
Karl A. Schmiedt, Fort Worth, Texas
James V. Howe, J. H. Jenkins, J. Earle Brown
Melbert E. Schwarz, Houston, Texas
John R. Suman, W. F. Bowman, David Donoghue
Maurice D. Scruggs, Ponca City, Oklahoma
J. V. Howell, Everett C. Parker, S. D. Butcher
Howard S. Splane, Pittsburgh, Pennsylvania
Roswell H. Johnson, R. E. Somers, S. G. Huntley
Constantine S. Stephano, Philadelphia, Pennsylvania
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
Charles H. Stewart, Waco, Nebraska
F. M. Van Tuyl, Chrales M. Rath, Max W. Ball
Raymond G. Travis, Stillwell, Indiana
F. M. Van Tuyl, Charles M. Rath, Max W. Ball
A. van Weelden, Houston, Texas
A. T. Schwennesen, F. E. Vaughan, John C. Myers
Cresap P. Watson, New York, New York
Alexander Deussen, W. E. Pratt, John R. Suman
Gavin Witherspoon, Jr., Bakersfield, California
E. J. Young, S. H. Gester, E. Huguenin
Basil B. Zavoico, New York City
C. G. Carlson, H. G. Officer, Carl S. Ford

FOR TRANSFER FROM ASSOCIATE TO FULL MEMBERSHIP

Frank T. Clark, Bartlesville, Oklahoma
A. F. Morris, E. P. Hindes, J. M. Nisbet
Clarence W. Hoffer, Olney, Texas
James F. Kemp, L. E. Trout, E. H. Sellards
Stirling Huntley, Pittsburgh, Pennsylvania
Roswell H. Johnson, R. E. Somers, S. G. Huntley
Arthur F. Turman, San Francisco, California
G. C. Gester, E. J. Young, S. H. Gester

SUPPLEMENTARY MEMBERSHIP LIST

The following men have been elected to membership or transferred from associate to full membership since the list was printed in the March-April number of Volume 9.

FULL MEMBERS

Blatchley, Raymond S., 924 Trust and Savings Bldg., Los Angeles, Calif.
Brandenthaler, R. R., 1653½ W. Thirty-eighth Place, Los Angeles, Calif.
Bucher, Charles E., Empire Co., Bartlesville, Okla.
Copley, Ralph D., Standard Oil Co., Production Dept., Inglewood, Calif.
Hardison, Harvey, Box 212, Coalinga, Calif.
Hiestand, Albert O., Pure Oil Co., Columbus, Ohio.
Klingaman, George L., 225 Bush St., San Francisco, Calif.
Lepper, G. W., Burmah Oil Co., Ltd., Brittannic House, Finsburg Circus, London, E.C. 2, England.
Logan, David M., Okmulgee, Okla.
Long, Carl T., Standard Oil Co., Standard Oil Bldg., Los Angeles, Calif.
McGirl, James N., 847 Mayo Bldg., Tulsa, Okla.
Marquardt, Ernest, 419 Lafayette St., New York, N.Y.
Murphy, Paul C., 1719 S. Detroit St., Tulsa, Okla.
Packard, Henry J., 516 Patterson Bldg., Denver, Colo.
Parrish, Gaston H., Mexican St. Clair Co., Apartado 241, Tampico, Tamps, Mexico.
Rau, Harold L., Box 2045, Carter Co., Tulsa, Okla.
Schwennesen, Alvin T., 543 First National Bank Bldg., Houston, Tex.
Sterrett, Douglas B., 239 W. Eleventh St., Tulsa, Okla.
Troxell, John N., Box 912, Tulsa, Okla.

ASSOCIATE MEMBERS

Absher, Kenneth B., 416 Chautauqua Ave., Norman, Okla.
Adams, J. V., Humble Oil and Refining Co., Wichita Falls, Tex.
Bruce, George H., Empire Co., Production Division, Oil Hill, Kan.

Cadle, Austin, Room 1523, Standard Oil Bldg., San Francisco, Calif.
Doolittle, Jefferson, 2525 Wilshire Blvd., Los Angeles, Calif.
Dorr, James B., Apartado 76, Tampico, Tamps, Mexico.
Engleman, Rolf, Tulsa, Okla.
Fralich, Charles E., 1604 Denniston Ave., Pittsburgh, Pa.
Headley, David J., 6 Deho Apartments, Winfield, Kan.
Henry, S. B., California Co., Colorado, Tex.
Hosterman, J. F., Amerada Petroleum Corp., Box 2022, Tulsa, Okla.
Hunt, Raymond S., Empire Co., Bartlesville, Okla.
Keyes, Wilson, Drawer 846, Colorado, Tex.
Koch, Thomas W., 403 Union Oil Bldg., Los Angeles, Calif.
Kreuger, Max L., Box 263, Prairie Oil and Gas Co., Tulsa, Okla.
MacDonell, James A., Box 2022, Amerada Petroleum Corp., Tulsa, Okla.
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Rathwell, Harold B., 4921 Cimarron St., Los Angeles, Calif.
Schmitton, M. B., Apartado 162, Tampico, Tamps, Mexico.
Schneider, G. W., 126 Jordan St., Shreveport, La.
Shakley, G. G., 435 Reynolds Ave., Kittanning, Pa.
Spangler, Grant W., Box 826, Winfield, Kansas.
Swiger, Rual B., Country Club Road, Fairmont, W.Va.
Taylor, Thomas G., Empire Refineries, Tulsa, Okla.
Thornburgh, H. R., Box 1865, Houston, Tex.
Torrey, Paul D., 3904 Forbes St., Pittsburgh, Pa.
Waters, James A., Sun Co., American Ex. Nat'l Bank Bldg., Dallas, Tex.
Weisbord, N. E., 227 Haven Ave., New York, N.Y.
White, Maynard P., International Petroleum Co., Tampico, Tamps, Mexico.
Woods, Hazen E., Texas Co., Wichita Falls, Tex.

TRANSFERRED FROM ASSOCIATE TO FULL MEMBERSHIP

Black, Glenn W., Union Oil Co. of Calif., Santa Fe Springs, Calif.
Case, W. B., Roxana Petroleum Corp., 928 Mayo Bldg., Tulsa, Okla.
Cheyney, A. E., Box 45, Eureka, Kan.
Classen, Willard J., Box 392, R.F.D., Menlo Park, Calif.
Dunlap, Gilmore S., Schaffer Oil Co., 729 Kennedy Bldg., Tulsa, Okla.
Evans, Noel, Box 682, Marland Refining Co., Ponca City, Okla.
Hummel, Henry L., Box 1116, Wichita, Kan.
Miller, Forrest J., Texas Co., Shreveport, La.
Nelson, Jean O., Standard Oil Co. of Indiana,Room 1111, 910 S. Michigan Ave., Chicago, Ill.
Ott, Emil, 237 N. Magdalen St., San Angelo, Tex.
Russom, Vaughn W., 709 Empire Masonic Bldg., Bartlesville, Okla.
Weirich, T. E., Skelly Oil Co., Tulsa, Okla.

PUBLICATION SCHEDULE OF THE BULLETIN

Following action by the Executive Committee of the Association in approving a change to monthly issue, beginning with the July issue of this year, a schedule of dates for the submission of manuscripts, return of proof and imprint of the *Bulletin* has been arranged. Delivery is planned for about the middle of each month. Minor contributions, including Geological Notes, Personal Items, Reviews, and contributions to the Round Table can be published in the number appearing forty-five days after the end of the month in which the contribution is sent to the Editor. That is, material of this sort received during August may appear in the October number. About sixty days is required for publication of a major contribution. Since consideration by the editorial board is necessary before transmittal to the publisher, an additional thirty days should be allowed for this.

REGIONAL DIRECTORS

New regional directors recently appointed are as follows: Eastern: Professor Roswell H. Johnson, University of Pittsburgh, Pittsburgh, Pennsylvania; North Mid-Continent: W. B. Wilson, Box 2044, Tulsa, Oklahoma; South Mid-Continent: R. B. Whitehead, 702 Magnolia Building, Dallas, Texas; Arkansas-Louisiana: A. F. Crider, 821 Ontario Street, Shreveport, Louisiana; Gulf Coast: David Donaghue, West Building, Houston, Texas; Rocky Mountain: Thomas S. Harrison, 1106 First National Bank Building, Denver, Colorado; Pacific Coast: Stephen H. Gester, 607 Standard Oil Building, San Francisco, California; Mexico: Walter M. Small, Apartado 76, Tampico, Mexico; Venezuela: Fred H. Kay, Apartado I, Caracas, Venezuela.

E. De Golyer

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

E. DeGolyer, vice-president and general manager of the Amerada Petroleum Corporation, 65 Broadway, New York, and president of this Association, delivered the commencement address at the Colorado School of Mines on May 15, 1925, the subject of his address being "The New Frontiers." It was considered one of the finest commencement addresses ever delivered at the school. In recognition of Mr. DeGolyer's standing as scientist, scholar, and executive, the School of Mines conferred on him the honorary degree of Doctor of Science.

Andrew N. Mackenzie has returned to Pasadena, California, from a geological investigation in Italy for the Sinclair interests.

W. W. Scott has been working on subsurface conditions in the Sarawah oil fields.

Sidney Powers, chief geologist for the Amerada Petroleum Corporation with headquarters at Tulsa, Oklahoma, visited the Shreveport, Louisiana, office in the early part of May.

Henry G. Schneider resigned his position as division geologist for the Amerada Petroleum Corporation at Shreveport, Louisiana, June 1, and is now with the geological department of the Dixie Oil Company at Shreveport. C. F. Hosterman, formerly in the Tulsa, Oklahoma, office of the Amerada, has been transferred to the Shreveport office as division geologist.

Elton Rhine has been appointed division geologist for the Empire Gas and Fuel Company with headquarters at Bartlesville, Oklahoma. Mr. Rhine covers the territory of northeastern Texas, southwestern Arkansas, and Louisiana.

Joseph M. Wilson, geologist for the Simms Oil Company at Dallas, Texas, made a brief trip to Shreveport, Louisiana, in May.

Edwin B. Hopkins, who has recently been in Venezuela, returned to New York about the middle of April, and is now on a trip to Mexico.

Among members of the Association who have recently been in New York are C. A. Fisher, Max Ball, James H. Gardner, Alexander Deussen, W. E. Wrather, and Sidney Powers.

Sidney Powers delivered the Oil Lectures at Harvard this spring.

W. E. Wrather, W. H. Twenhofel, A. C. Lane, H. D. Miser, David White, and K. C. Heald are among the members of the American Association of Petroleum Geologists who attended the meeting of the Division of Geology and Geography of the National Research Council in Washington, April 25.

Douglas R. Semmes, who recently made a geological examination in India, now has headquarters at Room 951, 25 Broadway, New York City. During the present summer he will spend most of his time in New Mexico in the interest of the Santa Fe Company, Farmington, New Mexico.

At a meeting of the Branner Club held on May 11, 1925, attended by many of the Los Angeles geologists, Dr. Franz Xavier Schaffer, of the University of Vienna, spoke on "The Quaternary Ice Age in the Light of New Investigations."

W. E. (Steve) Dunlap recently resigned from the General Petroleum Corporation to enter the employ of the United Oil Company in Los Angeles.

The Pan-American Petroleum Company moved on May 23, 1925, into the Petroleum Securities Building at Tenth and Flower streets, Los Angeles. This building, just completed, will house all of the Doheny companies.

Henry J. Hawley, of the Standard Oil Company of California, has been transferred from the Denver office to Los Angeles.

Edgar Kraus, geologist for the Atlantic Oil Producing Company, is at present in Roswell, New Mexico.

The Denver Institute of Technology, of the Young Men's Christian Association, is co-operating with the Colorado School of Mines in a short course of lectures on "Oil Refining." Professor R. C. Beckstrom, of the School of Mines, has been engaged to deliver a series of eight lectures one evening per week at the Young Men's Christian Association Building. This is probably the first time such a co-operative educational enterprise has been conducted in the field of petroleum engineering. The success of the course has been far beyond the expectations of the promoters. Through the co-operation of the oil refining companies of the city more than eighty-five students have been enrolled, fifty of whom come from one large company, which has paid the entire tuition fee for all of its employees who signified their desire to attend. Another company has enrolled twenty-five students on the same basis.

Professor Beckstrom is the head of the department of petroleum engineering of the Colorado School of Mines at Golden.

For over a year short-term classes in oil geology have been conducted by the Denver Institute of Technology with Professor F. M. Van Tuyl, also of the Colorado School of Mines, as the instructor. This has been a very popular course on account of the widespread interest in oil since its discovery in northern Colorado. Professor Van Tuyl covers his course in ten lectures with the aid of a large number of charts, slides, diagrams, and models. Nearly a hundred and fifty of Denver's citizens have been enrolled in this course. It is probable that next year a full eight months' course in the two subjects mentioned above, with Oil Production as an added course, will be offered by the Institute.

A geologists' luncheon was held at the Hotel Imperial, Tampico, May 6. D. J. Tynan, of the Tynan Diamond Drill Company, gave a very interesting talk on experiences in the desert of Western Australia. George L. Green, who has just returned from Yucatan, discussed the work of the American archaeologists on the peninsula.

The Geological Society of Tampico was organized on April 1, 1925. Officers elected were as follows: Walt. M. Small, Agwi, president; Paul Weaver, Aguila, vice-president; R. Leibensperger, secretary-treasurer; A. H. Noble, chairman of Committee on Publications; Paul Weaver, chairman of Technical Committee.

Mr. and Mrs. A. E. Fath sailed for Europe in March, in the interest of the Vacuum Oil Company.

Philip H. Austin, who has been engaged in valuation appraisal for the Philadelphia Company, has accepted a position in the geological department of the Shaffer Oil Company, Tulsa, Oklahoma.

Russell S. Knappen is doing geological work for the United States Geological Survey in Southwestern Alaska. His headquarters are at Chignik.

Clifton S. Corbett has resigned his position as associate professor of geology at the University of Kansas to accept an appointment as geologist for the Standard Oil Company of New Jersey in the Dutch East Indies. He sailed from New York in June for his new headquarters in Batavia.

Dr. Donaldson Bogart Dowling, sixty-seven years of age, died in Ottawa in June. He entered the Geological Survey of Canada in 1884 and during the last fifteen years had devoted most of his time to the structural geology of the Great Plains in furtherance of the search for oil which followed the Calgary boom. His reports on the southeastern artesian basin are authoritative for that extensive portion of Canada. Dr. Dowling was one of the leading geologists of America, a careful observer, and a staunch friend of the young geologists seeking to make their way. He will long be remembered for his untiring efforts to further the development of the mineral resources of the Dominion. He was a Fellow of the Geological Society of America, member of the Canadian Institute and other scientific societies.

With no small shock and with deepest sorrow we have learned of the death, on Friday, May 29, 1925, of Dr. John Mason Clarke, whose lifetime of service in studies of the geology and paleontology of New York has left an indelible record on North American geology, and whose brilliant scholarship and delightful personality made him an outstanding figure among the scientists of his time. It was indeed a special pleasure and opportunity to have enjoyed his presence at the Wichita meeting of the Association so short a time before his death. Most sincerely do we mourn his death.